ADVISOR and the Digital Functional Vehicle Process for Analysis of HEVs

HEV Workshop, Austin, TX
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Golden, Colorado

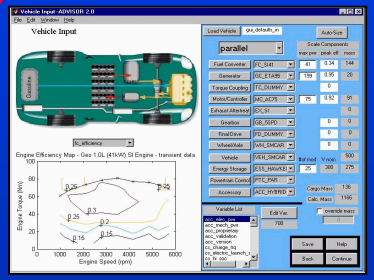
NREL, Center for Transportation Technologies and Systems

Outline

- Background and Capabilities of ADVISOR
- Demonstration of ADVISOR 3.2
- Optimization of a Fuel Cell SUV
- Digital Functional Vehicle
- Bonus: Thermal Effects on Batteries

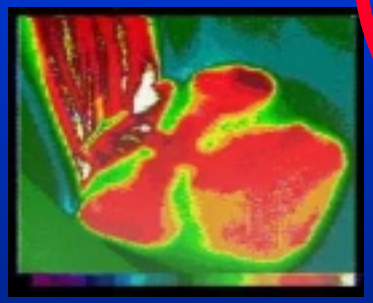
Hybrid Electric Vehicle Program at NREL Involves 3 Main Areas of Emphasis

ADVISOR

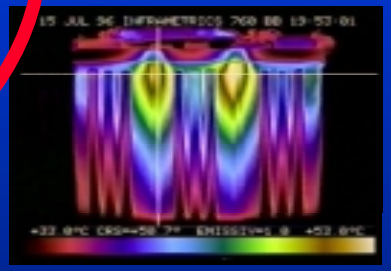


Digital Functional Vehicle

Vehicle Systems Analysis



Vehicle Auxiliary Load Reduction



Battery Thermal Management

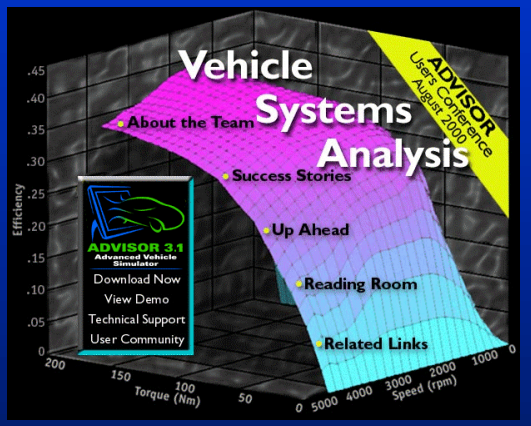
Big 3 Partnership

HV program: 55 mpg

PNGV: 80 mpg goal

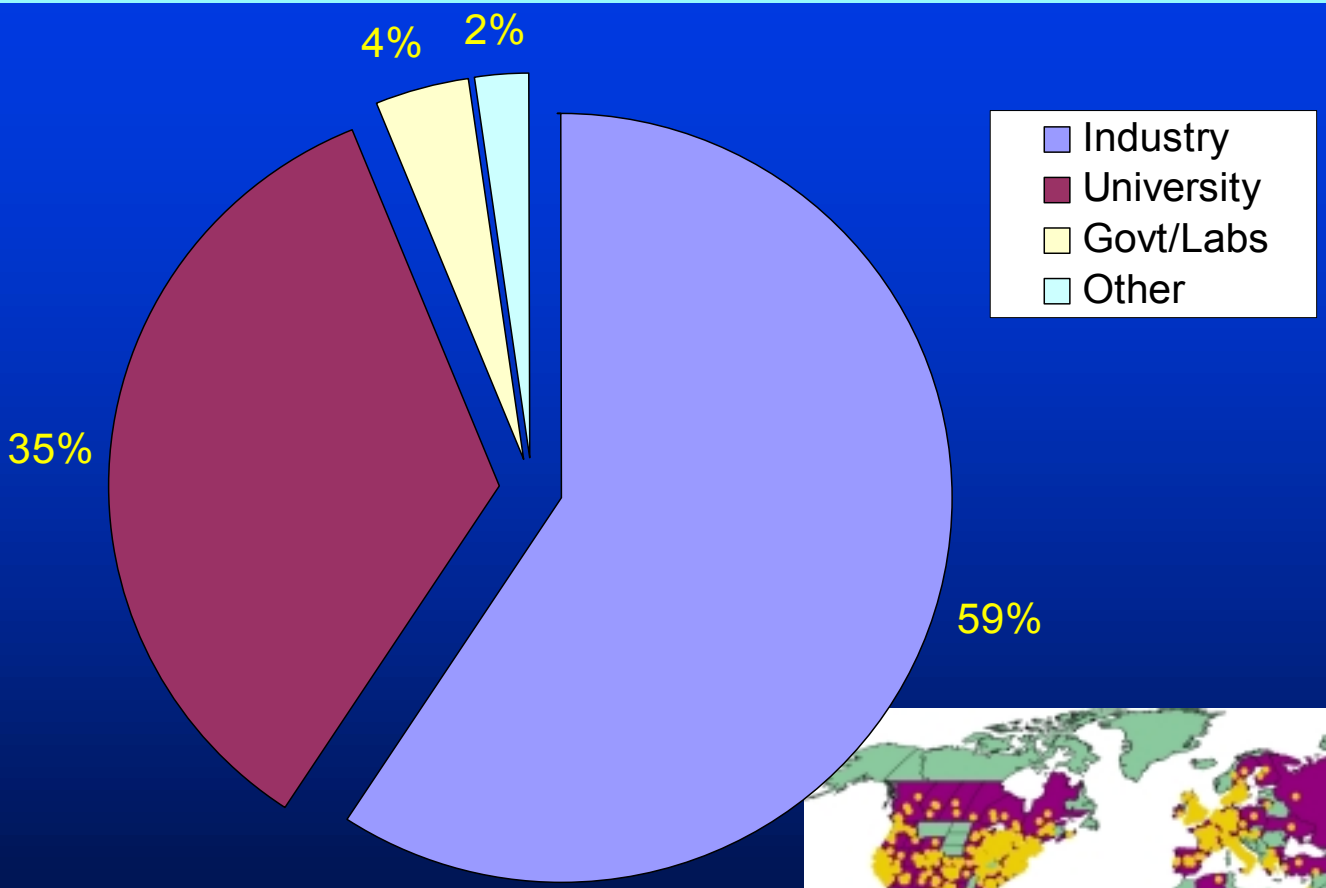
Background on ADVISOR

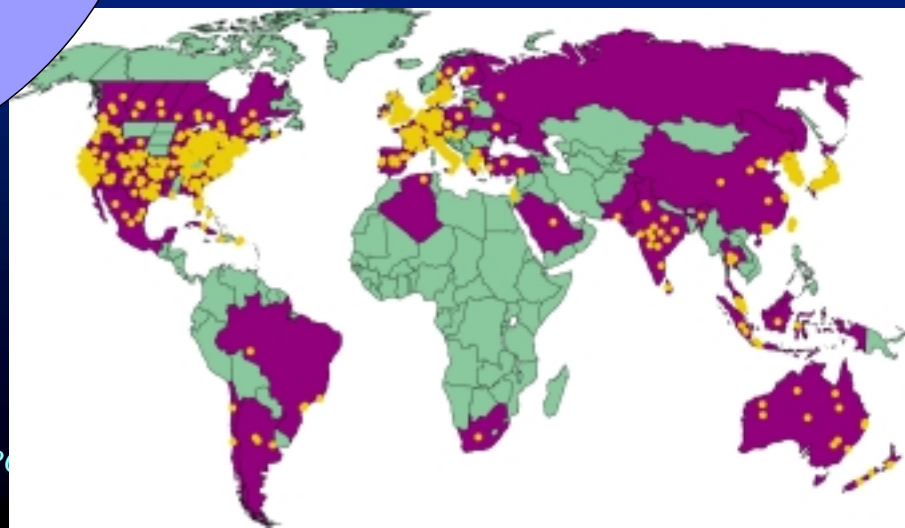
- ADVISOR = ADvanced VehIcle SimulatOR
  - simulates conventional, electric, or hybrid vehicles (series, parallel, or fuel cell)
- ADVISOR was created in 1994 to support DOE Hybrid Program at NREL
- Released on vehicle systems analysis web site for free download in September, 1998



- Downloaded by over 3700 people around world
- Users help provide component data and validation, feedback for future development

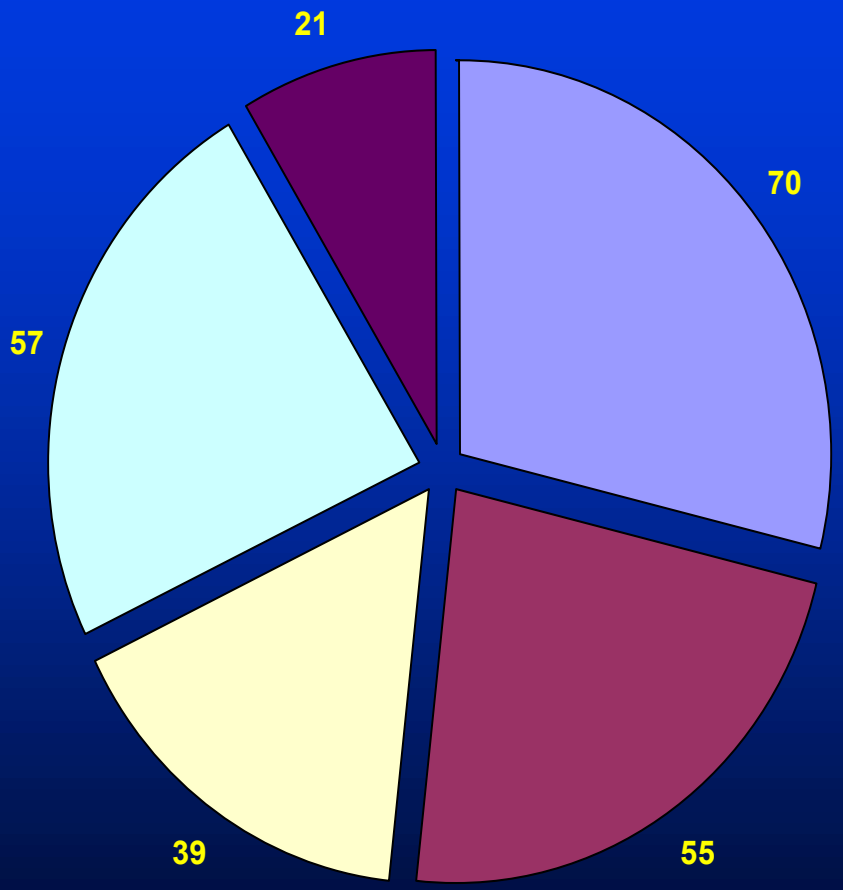
ADVISOR Being Used Globally by >3700 Users
Significant ADVISOR Usage by Industry





NREL, Center for Transp

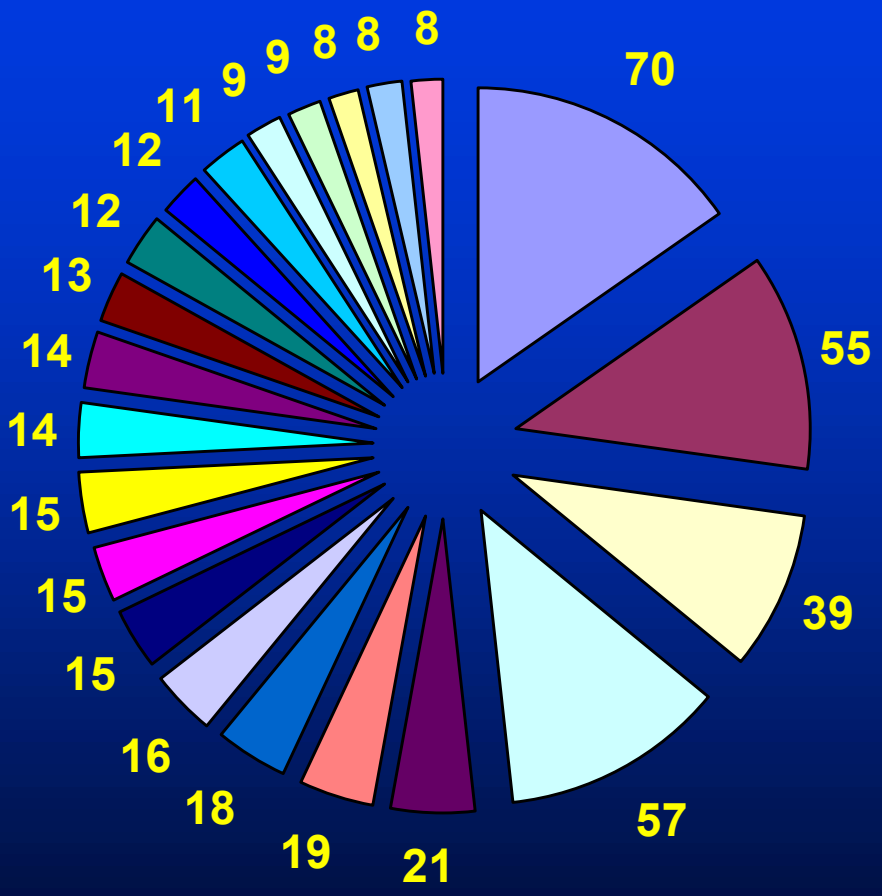
The US Auto Industry is Using ADVISOR and has a Major Investment in its Usage



- Ford Motor Company
- DaimlerChrysler Corporation
- General Motors
- Visteon
- Delphi Automotive Systems

As of 6/15/01

All Major OEMs and Suppliers Have Spent Some Time with ADVISOR

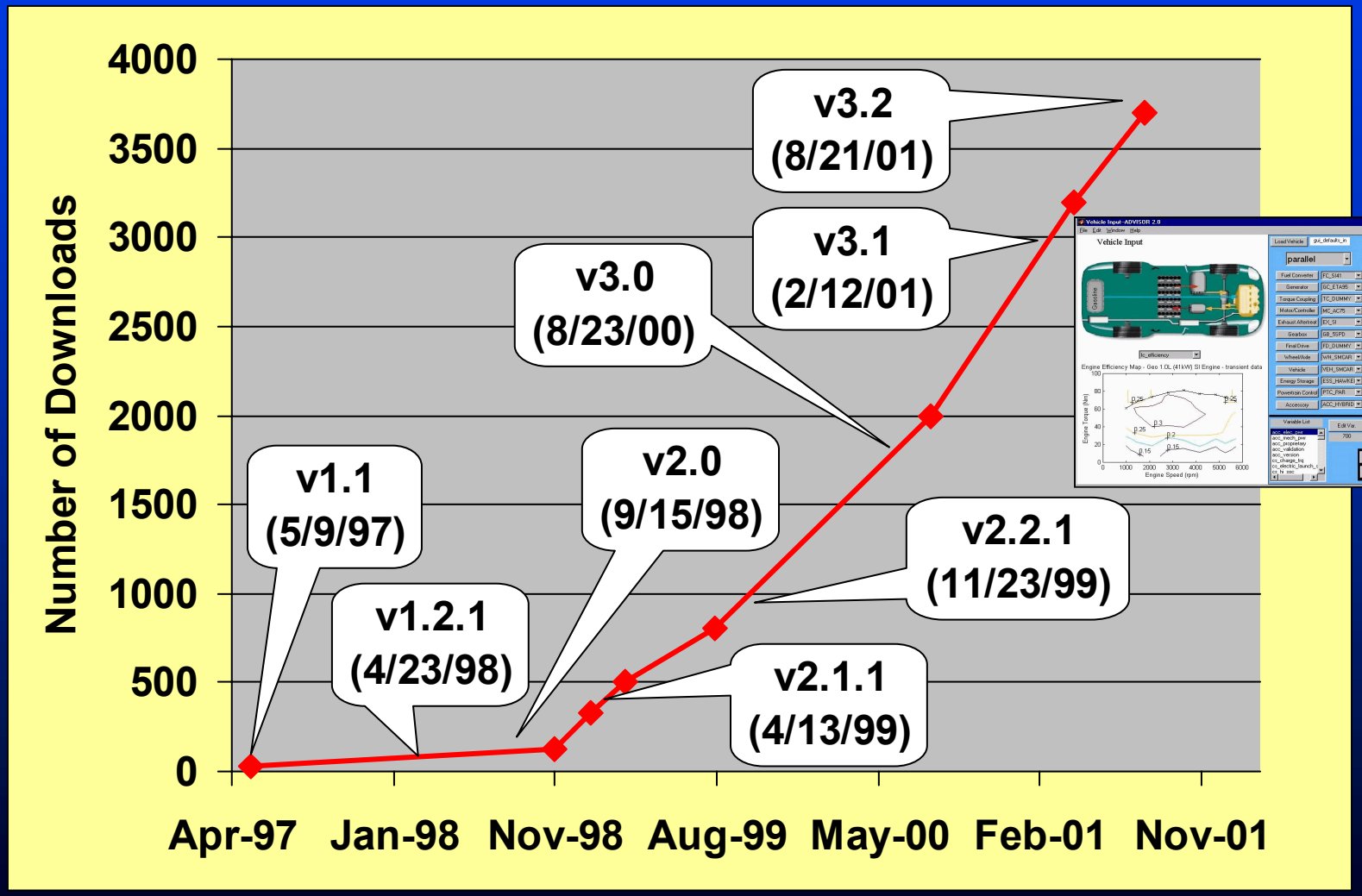


- Ford Motor Company
- DaimlerChrysler Corporation
- General Motors
- Visteon
- Delphi
- Volvo
- Hyundai Motor Company
- Hitachi Ltd.
- Eaton Corporation
- Siemens Automotive Systems
- Fiat
- Honda
- Mathworks
- Ricardo, Inc.
- FEV Engine Technology
- Nissan Motor Company
- AVL
- Toyota Motor Corporation
- Robert Bosch
- Parametric Technologies Corp.
- TNO Automotive
- Mitsubishi Motors Corporation

Legend includes organizations with 8 or more users

As of 9/4/01

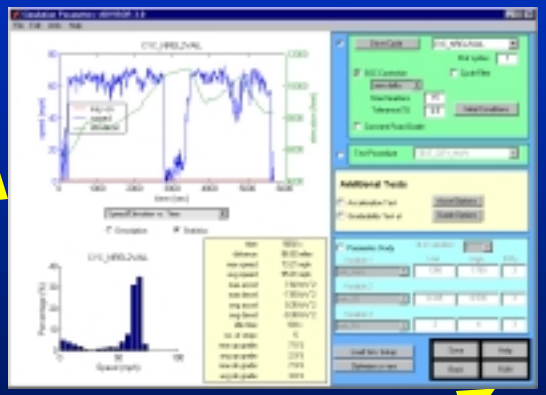
Total Number of ADVISOR Users Continues to Grow at a Steady Rate



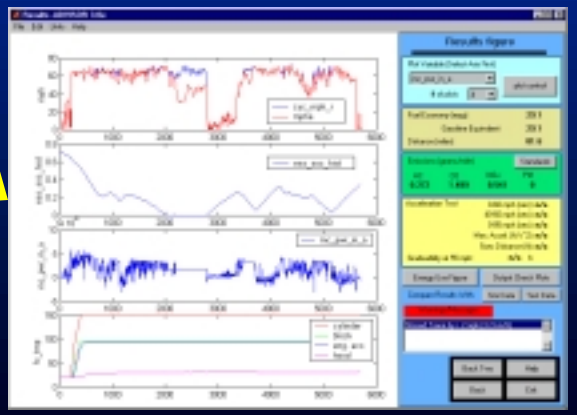
Three Main ADVISOR Screens (Roadmap)

Vehicle Input

Simulation Setup

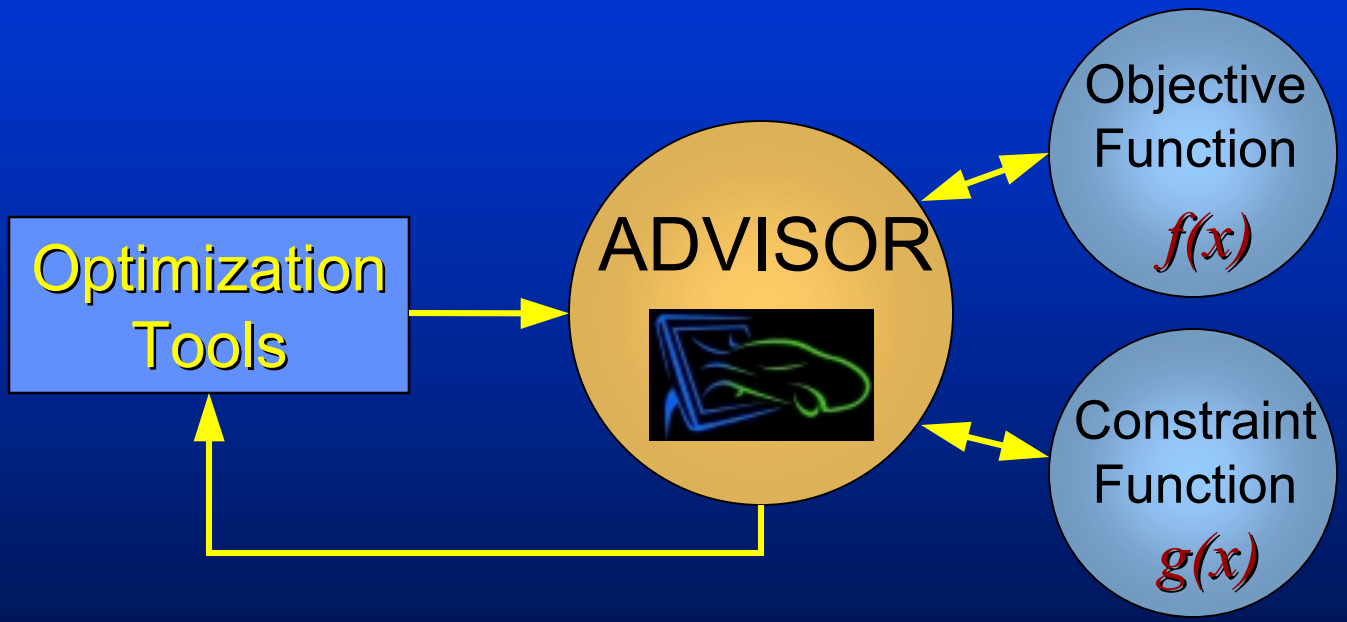


Results

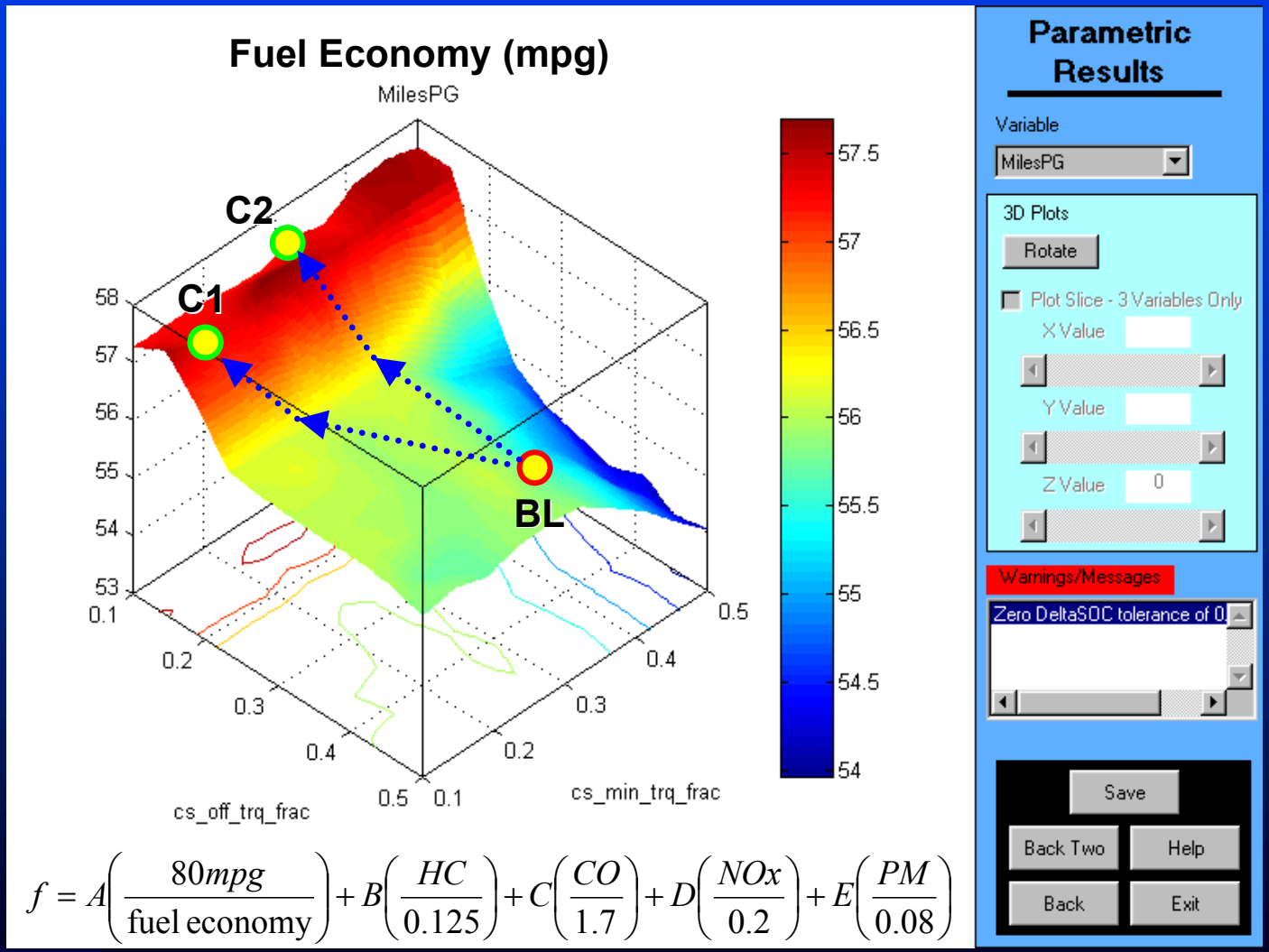


ADVISOR Demonstration

Using ADVISOR in an Optimization Loop



Optimization Allows Complex Trade-Offs to be Performed Numerically

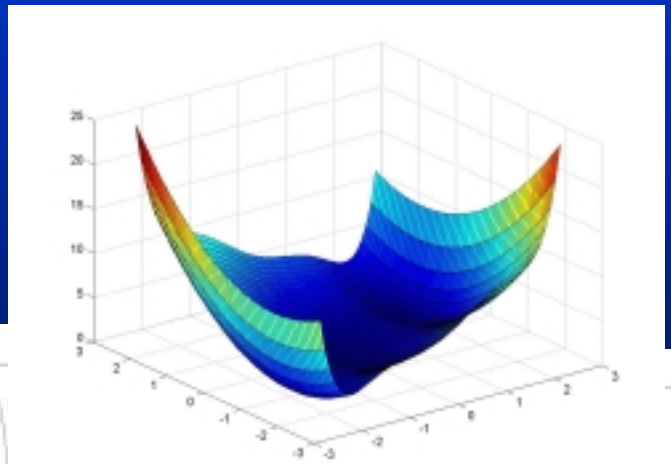


$$f = A\left(\frac{80mpg}{\text{fuel economy}}\right) + B\left(\frac{HC}{0.125}\right) + C\left(\frac{CO}{1.7}\right) + D\left(\frac{NOx}{0.2}\right) + E\left(\frac{PM}{0.08}\right)$$

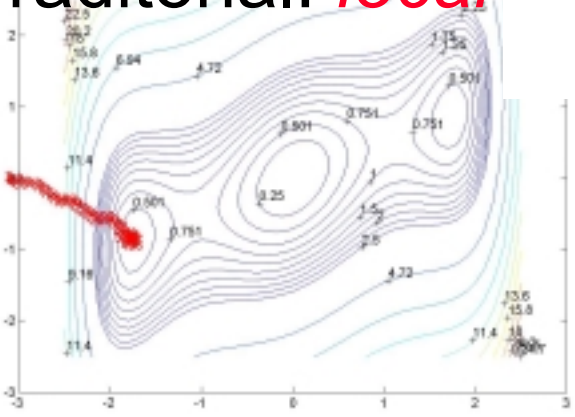
Applying Optimization Techniques

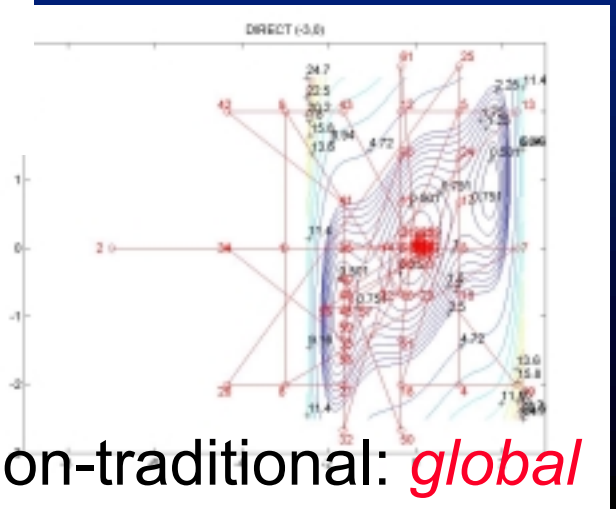
Example: *Fuel Cell Hybrid SUV*

- Maximize fuel economy of Fuel Cell Hybrid SUV
- Coupling of sizing with control strategy leads to improved solution (56.5 mpgge, up from starting point of 41 mpgge)
- Multiple local optimums in HEV design space



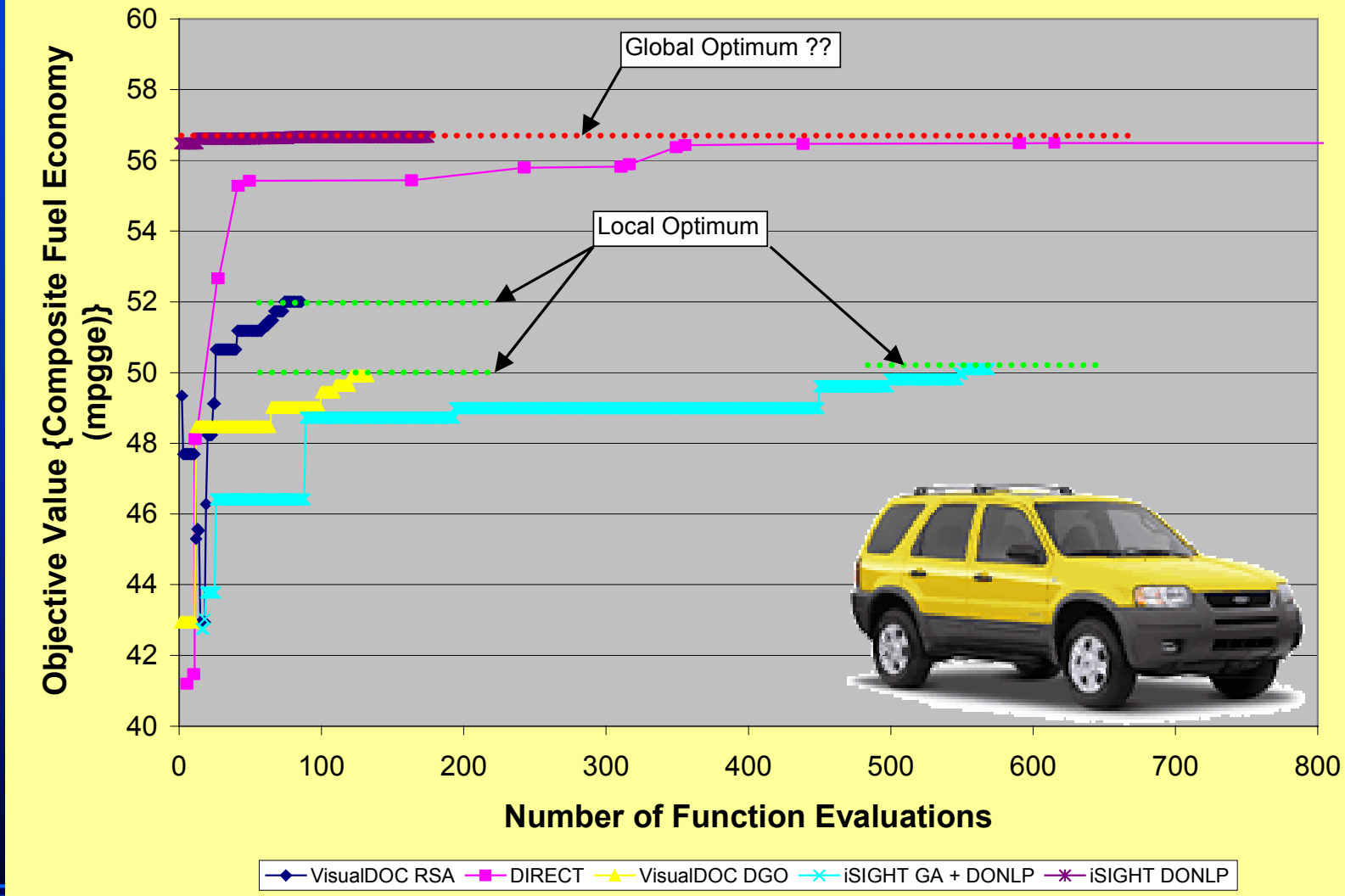
Traditonal: *local*





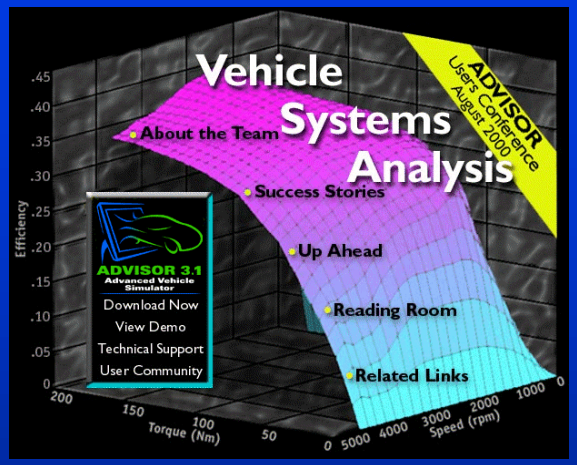
Non-traditional: *global*

Complex Design Space of Hybrid Fuel Cell Vehicles Has Local Optimum, and Requires Multi-algorithm Approach to Find Global Solution



ADVISOR Availability on Web

- NREL's Vehicle Systems Analysis web site launched in September 1998
- ADVISOR 3.2 available for free after filling out simple form
- 'Forum' has bulletin area for questions to be answered and files to be shared
- Documentation viewable from web site
- Reading room has all papers and presentations from team
- www.nrel.gov/transportation/analysis



Clockwise: Ken Kelly, Sam Sprik, Keith Wipke, Tony Markel, Valerie Johnson, Aaron Brooker, Terry Hendricks

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Digital Functional Vehicle

What is it?

A collection of integrated software modeling tools and processes that enable the evaluation, design and optimization of new energy saving automotive technologies such as HEVs and Fuel Cells.

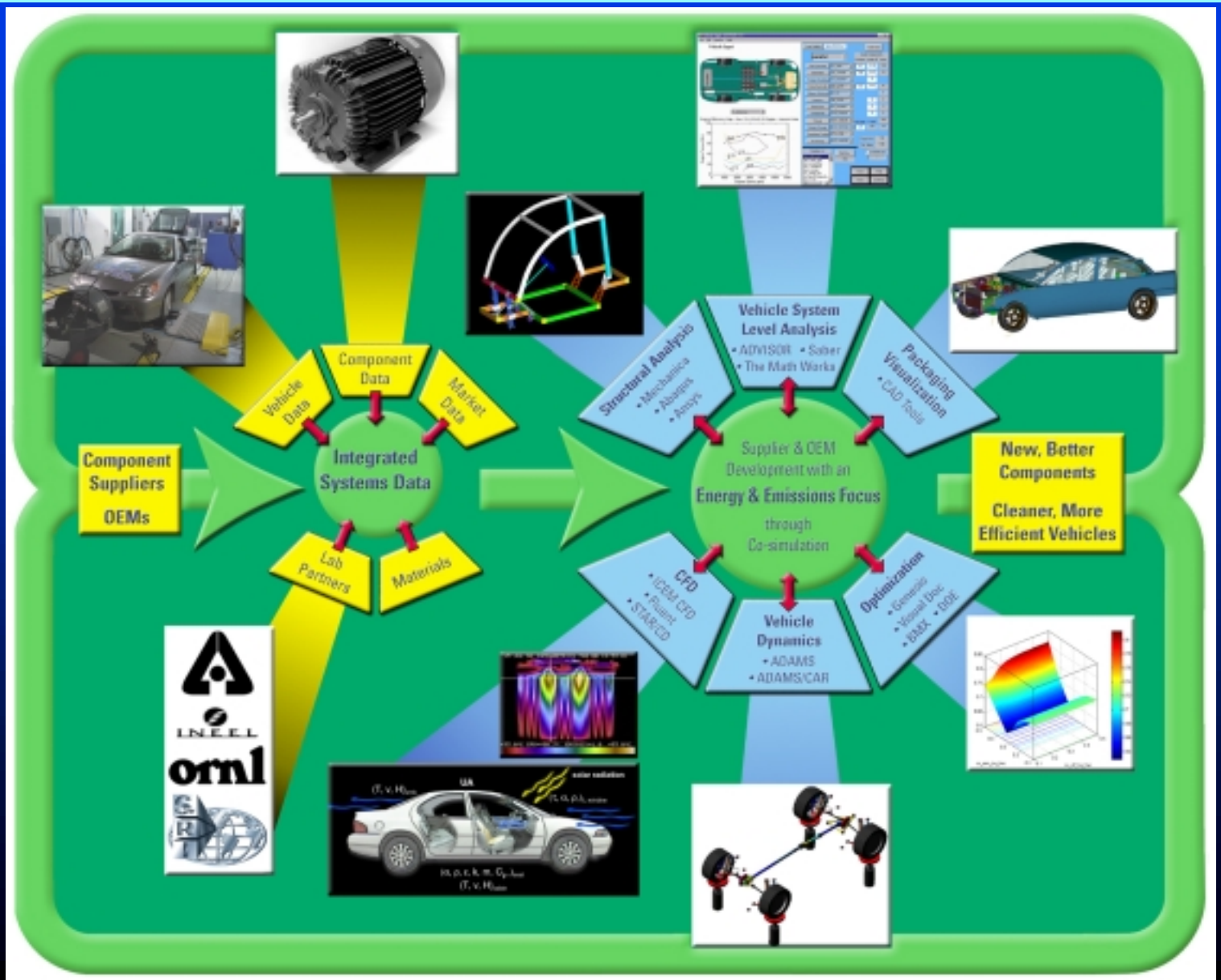
Why?

NREL and their automotive industry partners work together to identify and remove technical barriers of these technologies.

What is new?

Simulation, modeling, safety and costing tools are readily available to the automotive industry. What is missing is a workable synergy between these tools to make them effective enablers of new technologies.

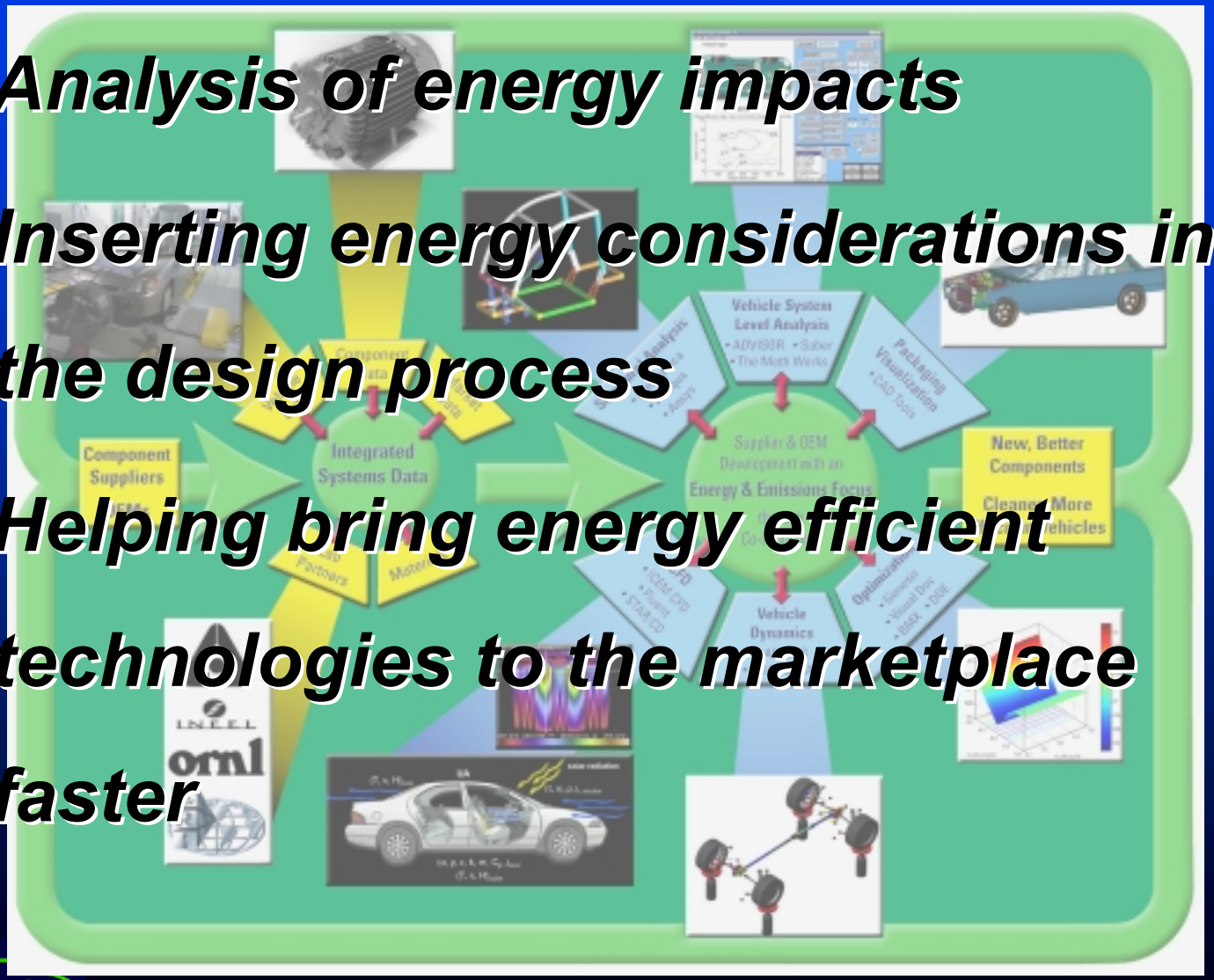
Vision: Digital Functional Vehicle Process



Digital Functional Vehicle

Integrating & Applying the Latest Computer Modeling Tools for Real-World Energy Solutions

- ***Analysis of energy impacts***
- ***Inserting energy considerations into the design process***
- ***Helping bring energy efficient technologies to the marketplace faster***



NREL Vehicle Systems Analysis Team's Industrial Partners

OEMs

GM

Ford Motor Company

DaimlerChrysler

Major Suppliers

Visteon

DELPHI Automotive Systems
Driving Tomorrow's Technology

Software Companies

Engineous Software Inc.

XR&D

Mechanical Dynamics
The world's leader in functional virtual prototyping

Avant!

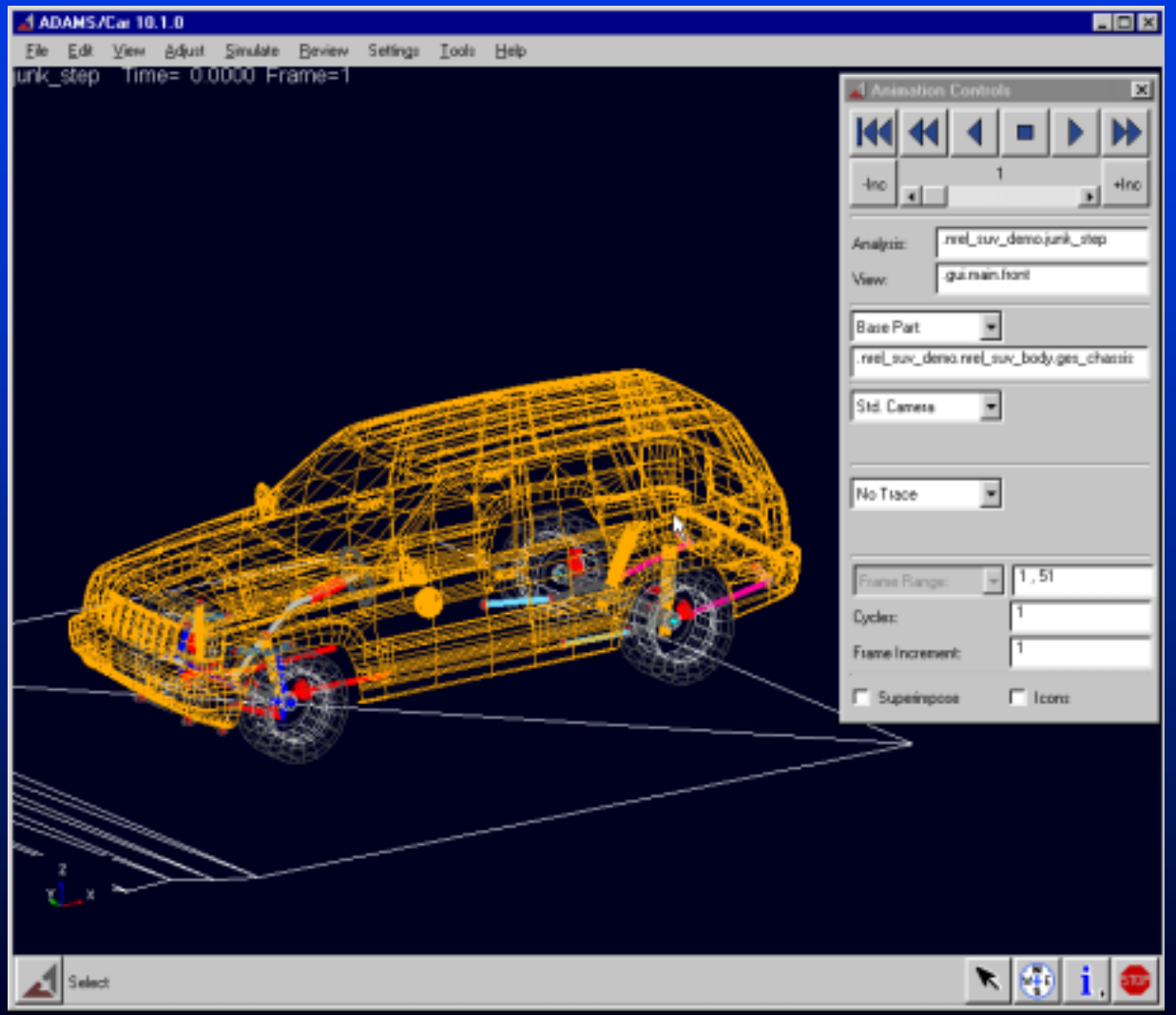
The MathWorks

(minimize custom coding; maximize usage by industry of resulting improvements)

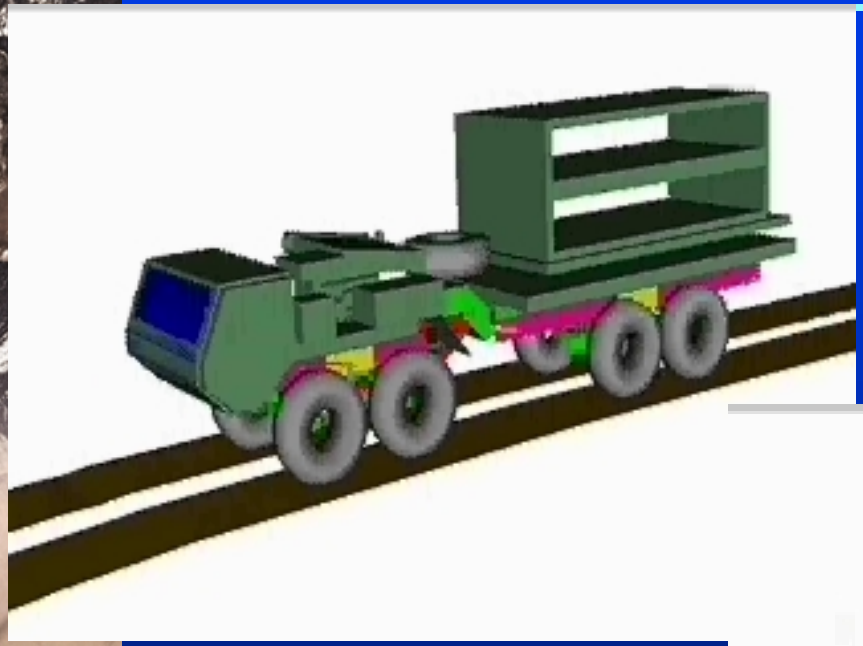
ADAMS/Car – ADVISOR Linkage

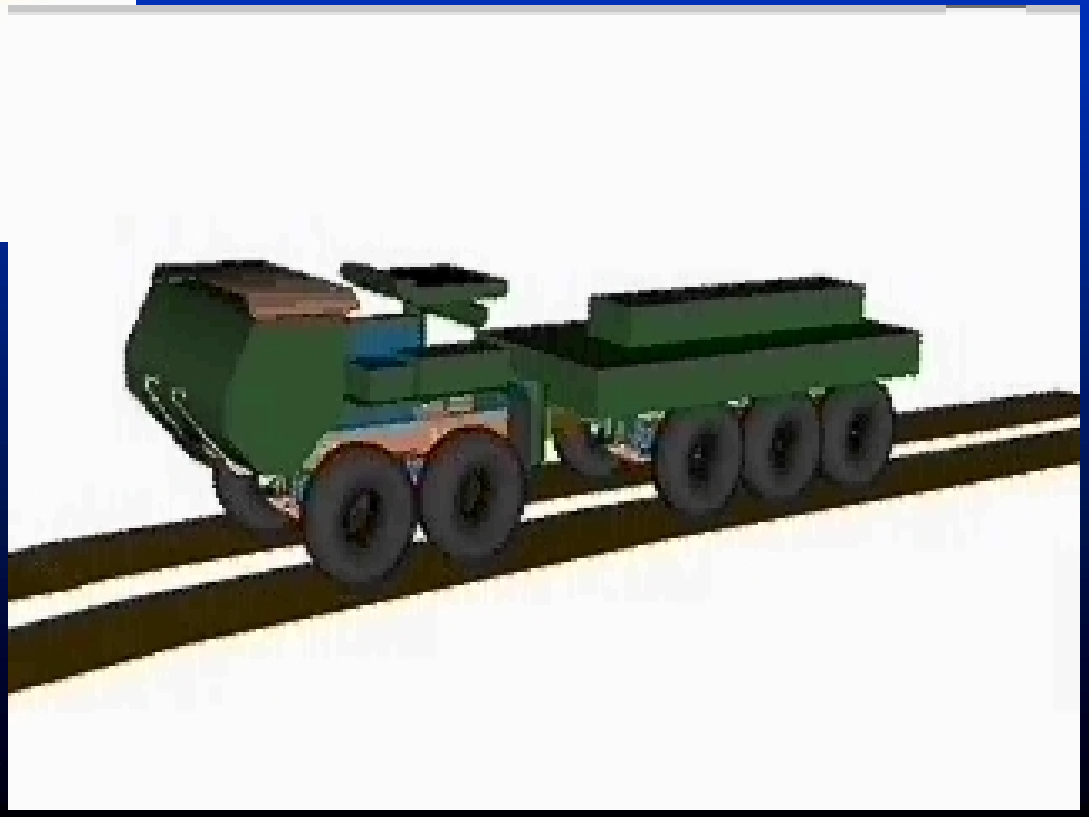
Enables Advanced Powertrains to be Simulated with any ADAMS/Car model

- ADVISOR Models:
  - Fuel Economy
  - Drive Train
- ADAMS/CAR Models:
  - Road Vehicle Contact
  - Suspension



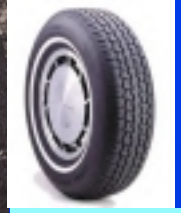
This New Co-Simulation Enables Advanced Powertrains to be Simulated with any ADAMS/Car model





[Videos courtesy of MDI]

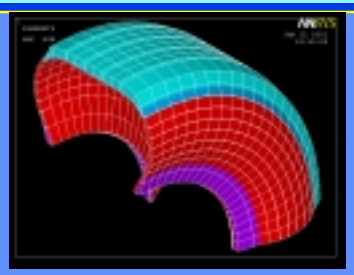
NREL, CENTER



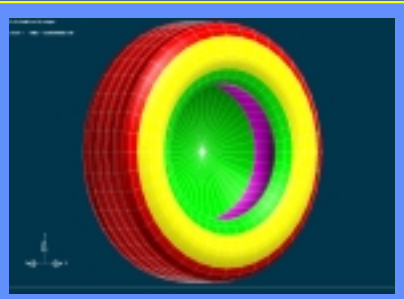
Need for Good Tire Model -- Tire Modeling at NREL

Industry Partner:
Major US OEM

NREL Parametric Tire Data
(Geometric, Material, Loading, Modeling)

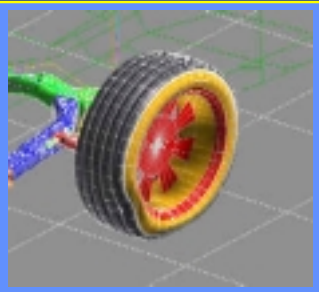


Parametric Solid Model



FEA Model

Execution at ORNL Supercomputer

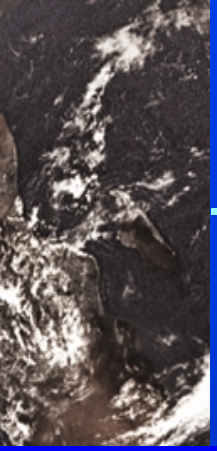


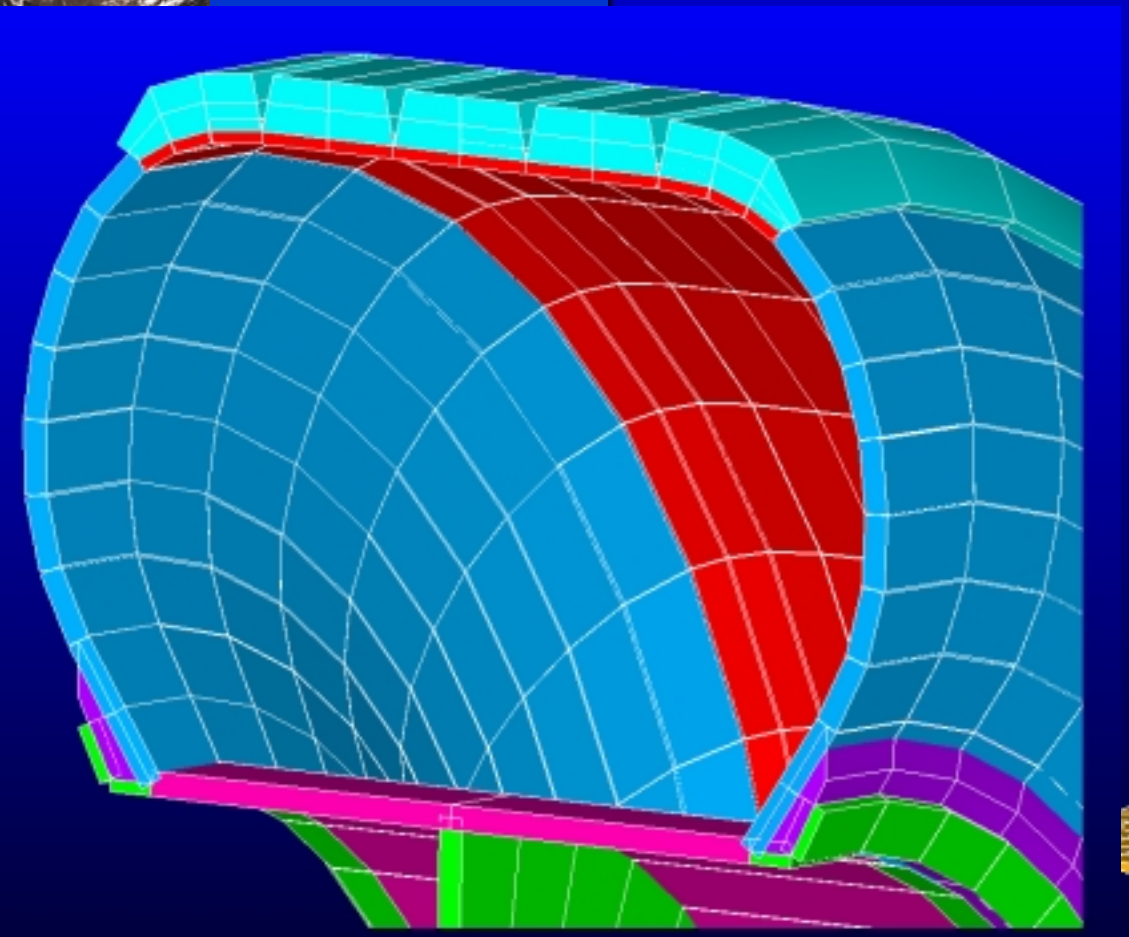
FEA Results

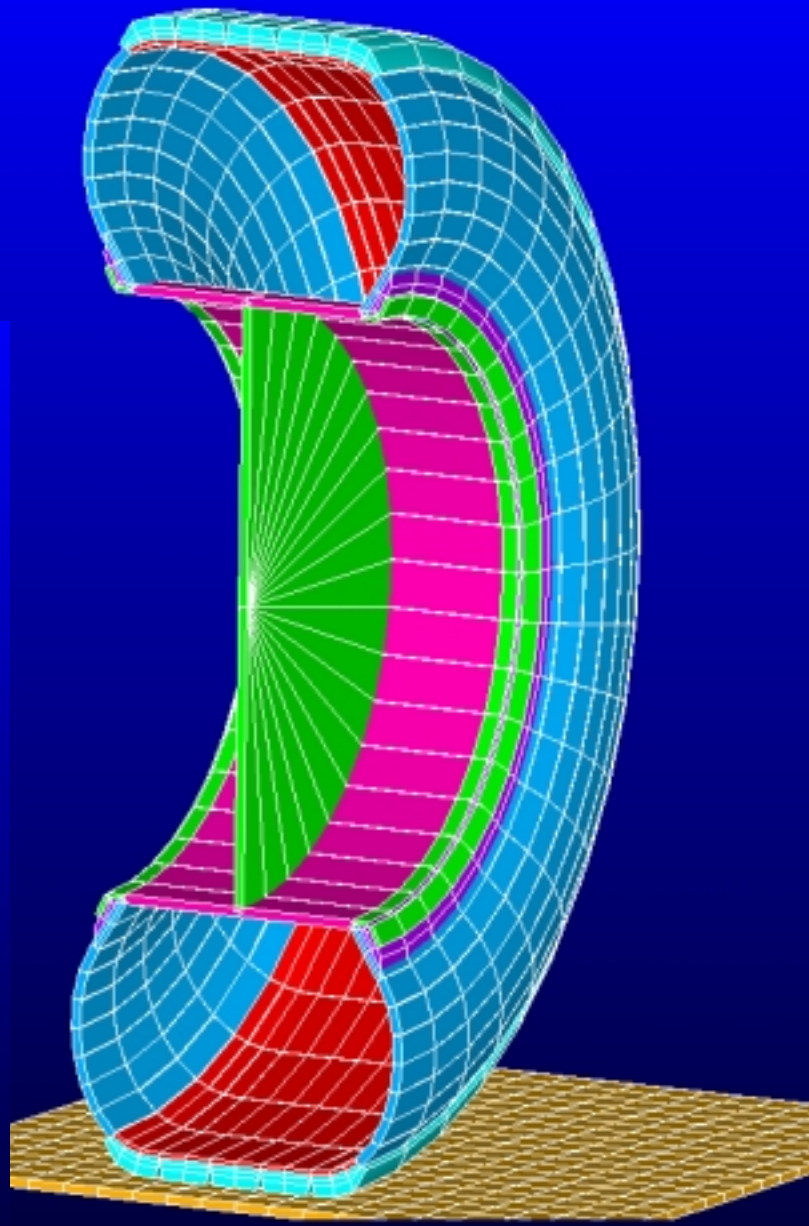
DOE
Optimization
Enrich - Data Base

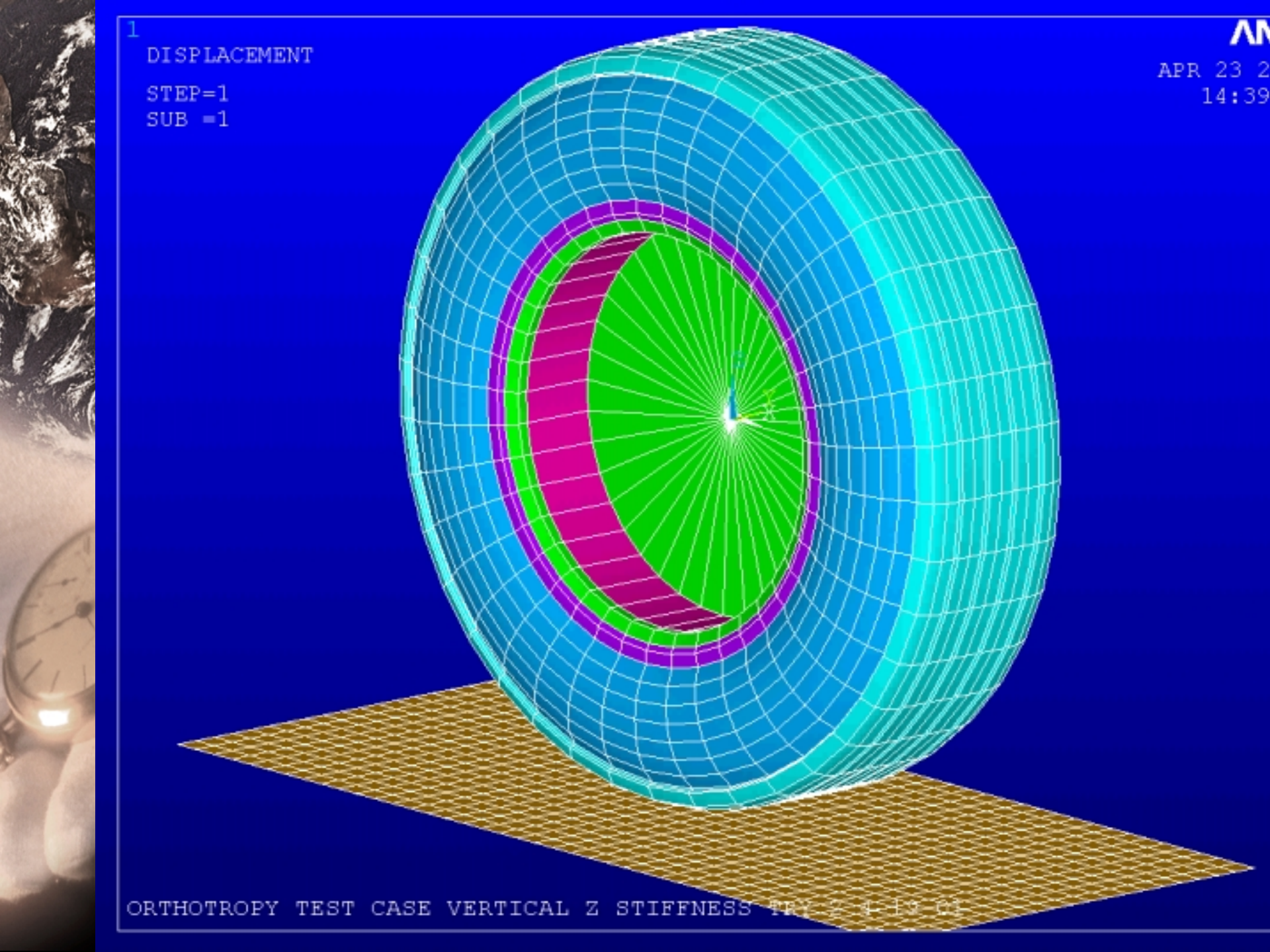
- Improving the loads prediction capability using an accurate tire model will assist in minimizing vehicle weight while creating durable vehicle structure

Tire FEA ½ Model for Road Load Prediction

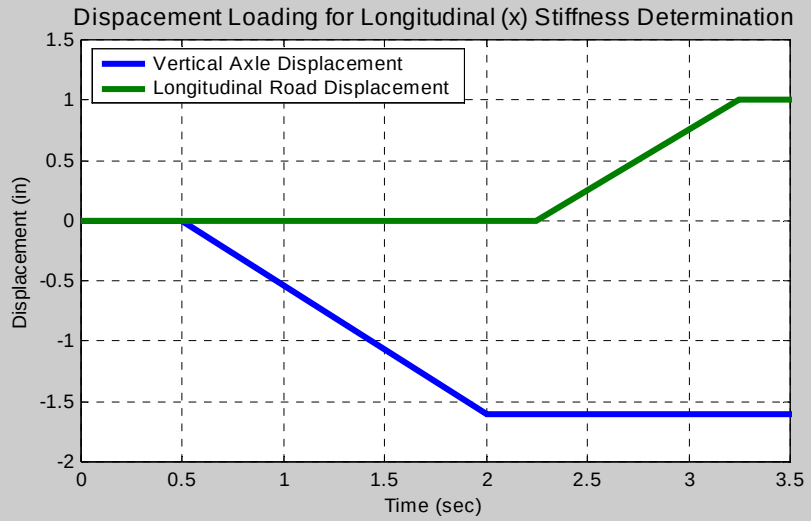


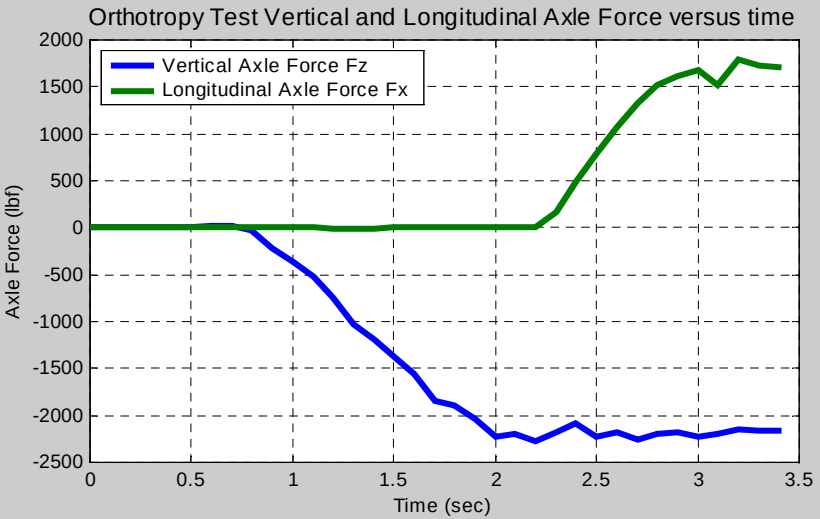


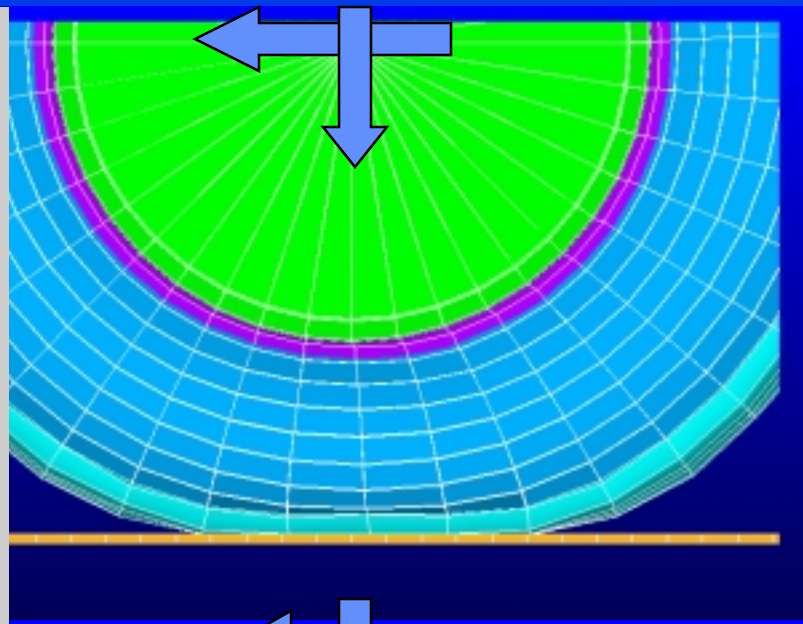


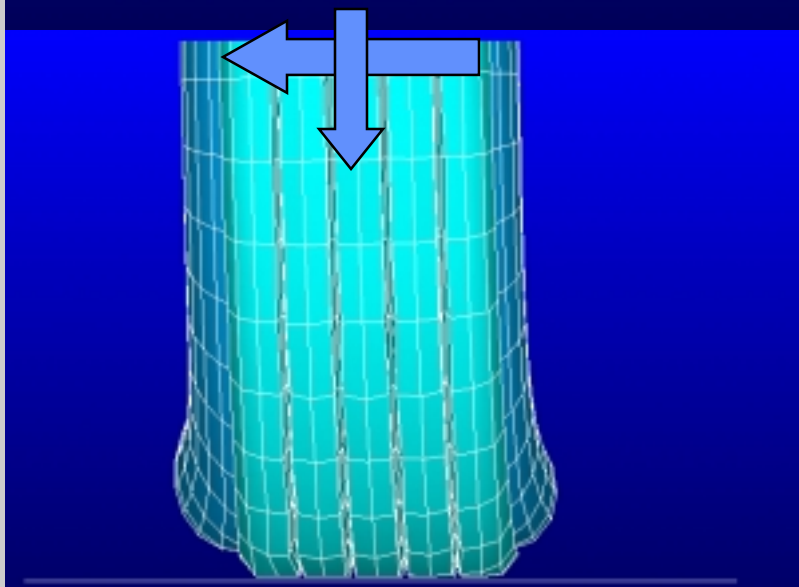

1
DISPLACEMENT
STEP=1
SUB =1
APR 23 2
14:39
ORTHOTROPY TEST CASE VERTICAL Z STIFFNESS

Vertical, Lateral & Longitudinal Stiffness determination



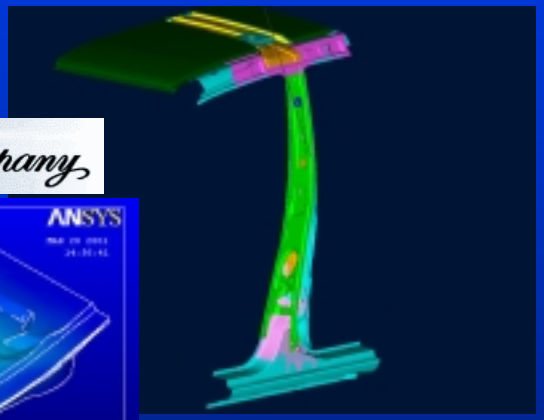




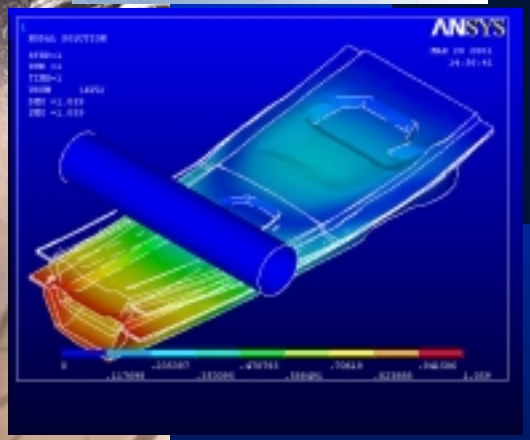


Other Recent DFV Applications

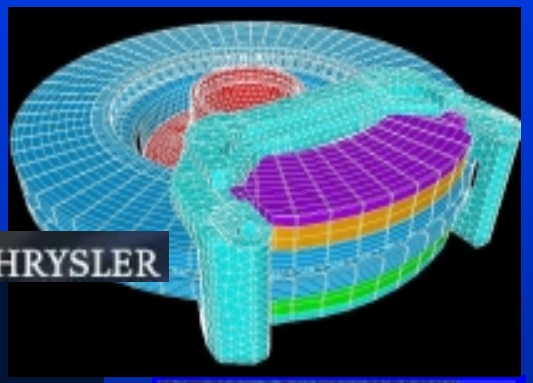
Use of Aluminum in vehicle structural components



Ford Motor Company



Alternatives in brake system cooling



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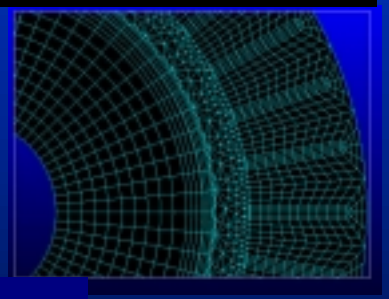
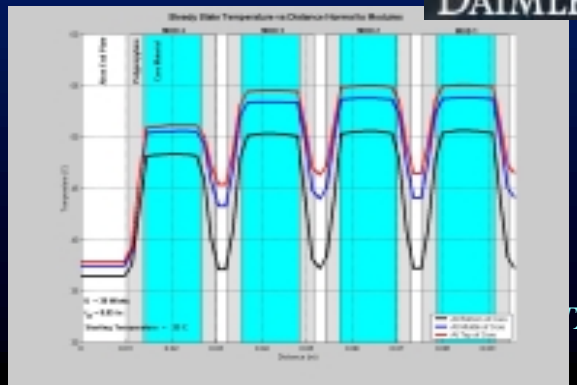


Battery thermal management strategies



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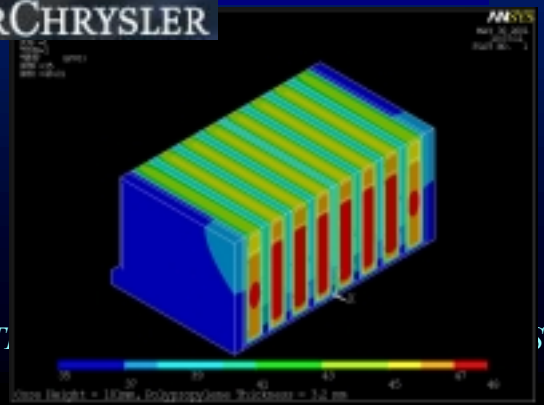


Structural foam Applications for Side-impact Crashworthiness

B-pillar location

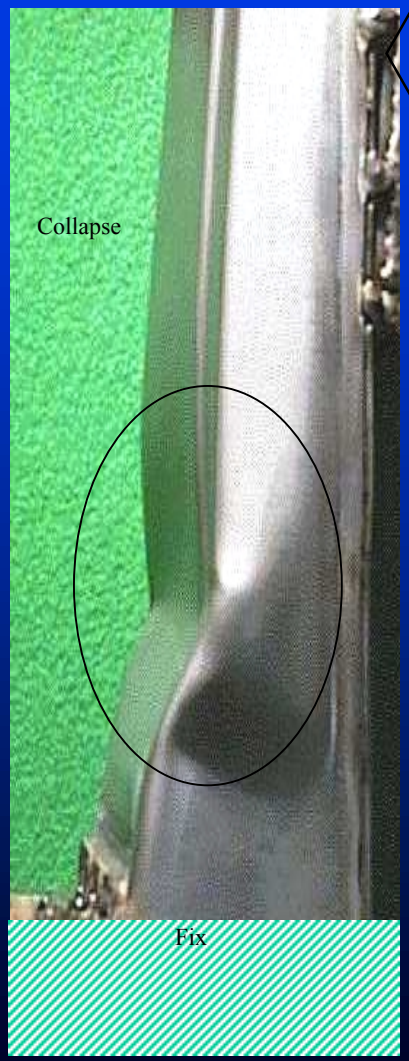
No Foam

Collapse by local buckling

With Foam

Local buckling prevented

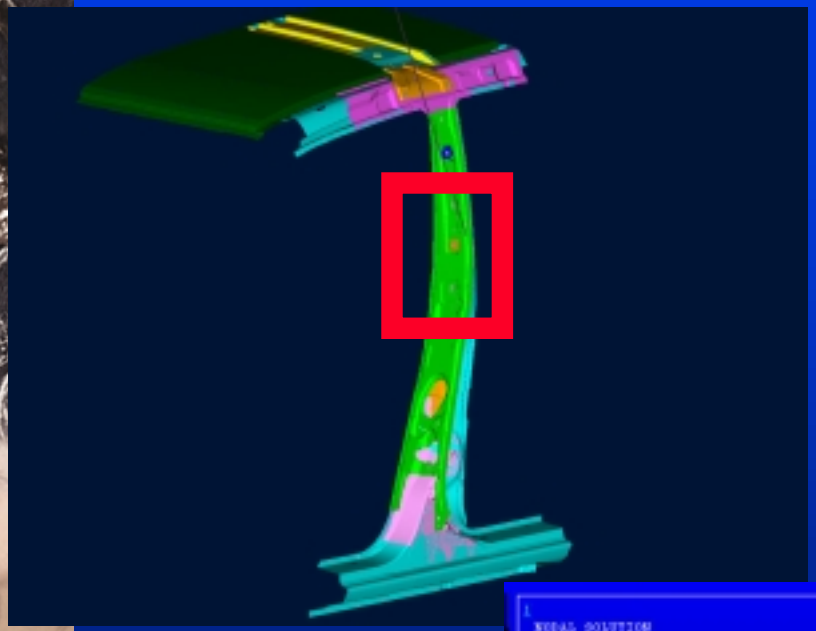
B – Pillar experiments with and without foam

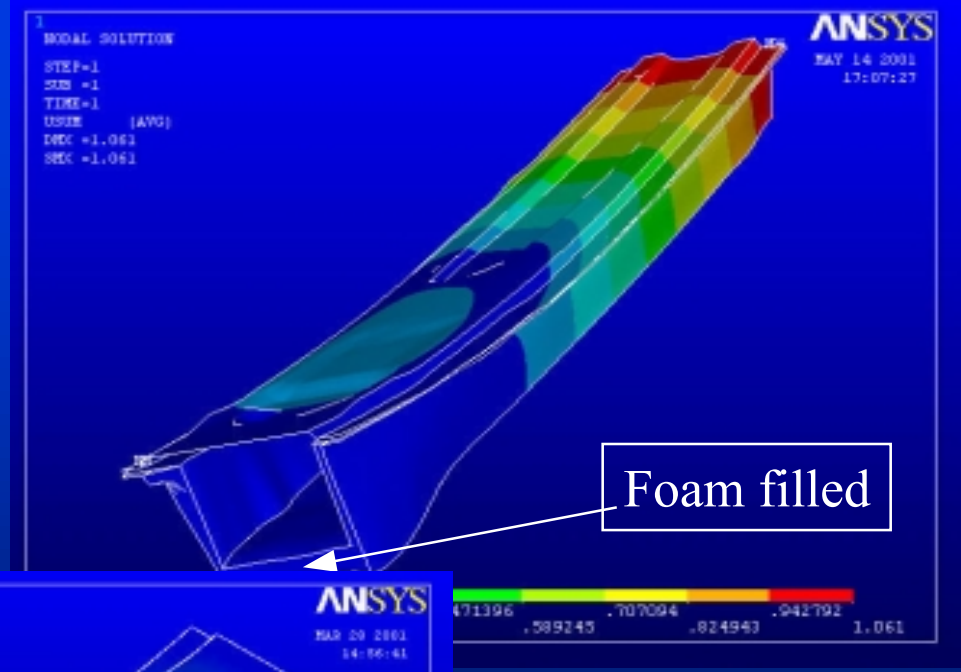


Auto Body Weight Reduction with Modular Aluminum Components Partially Filled with Structural Foam

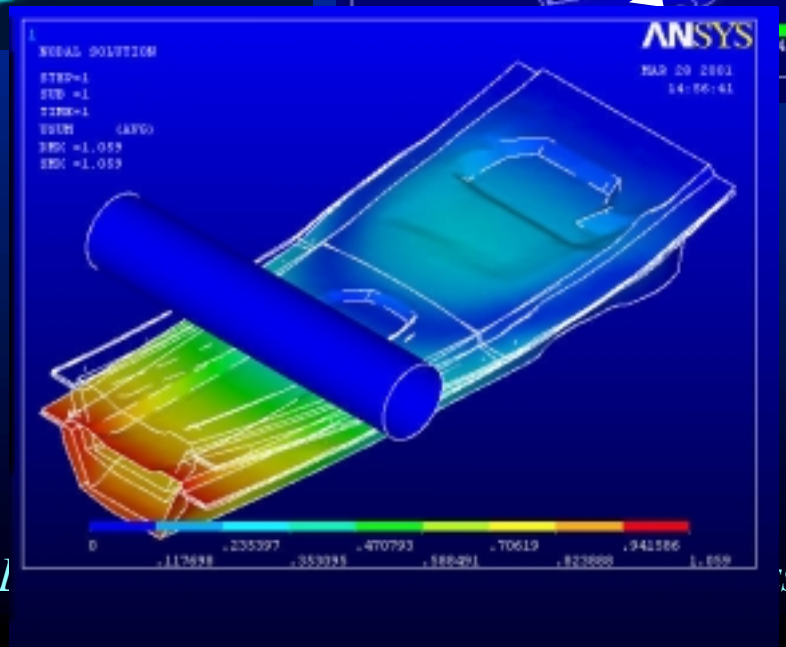
Industry Partner

Ford Motor Company

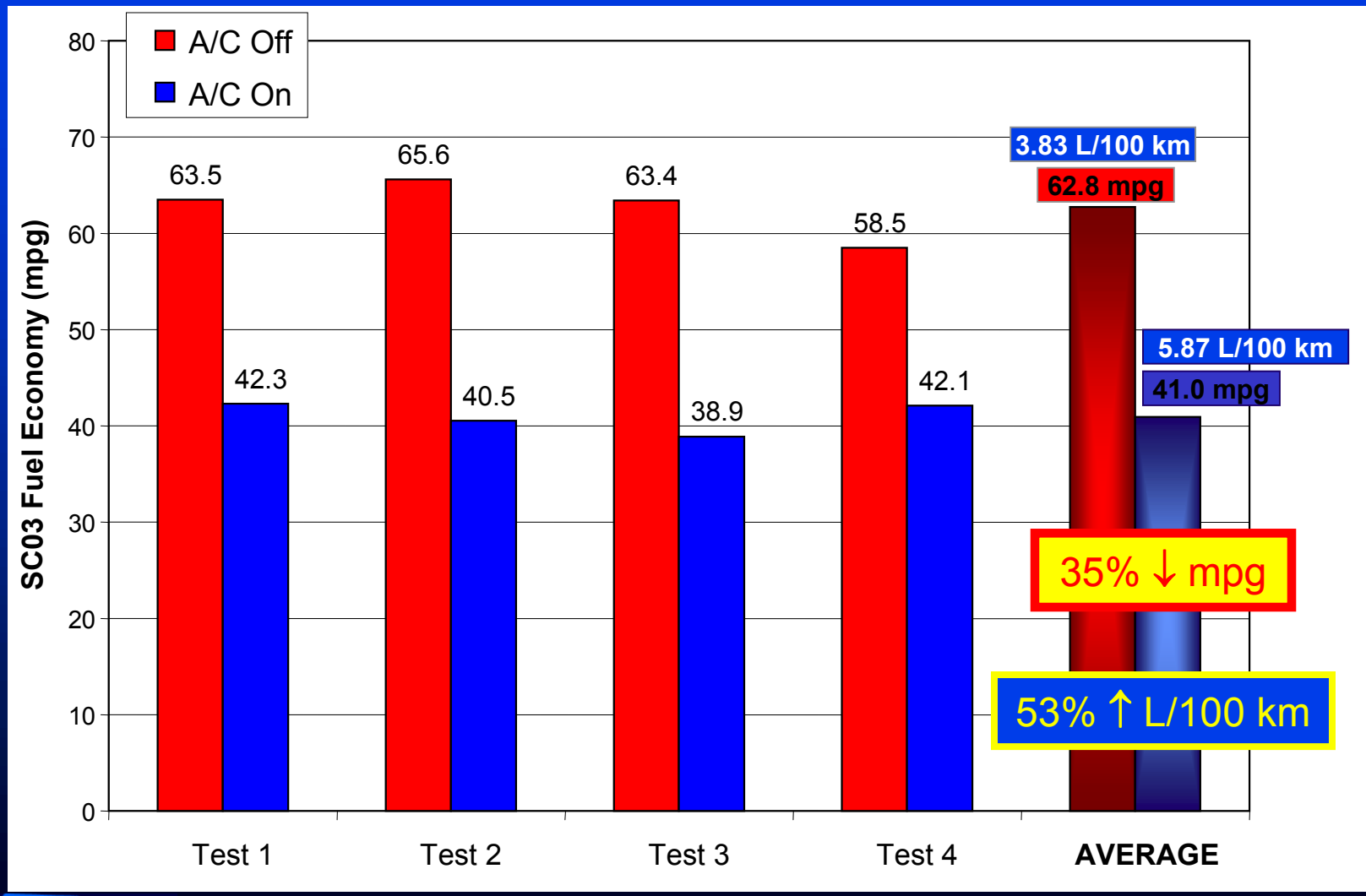




Foam filled

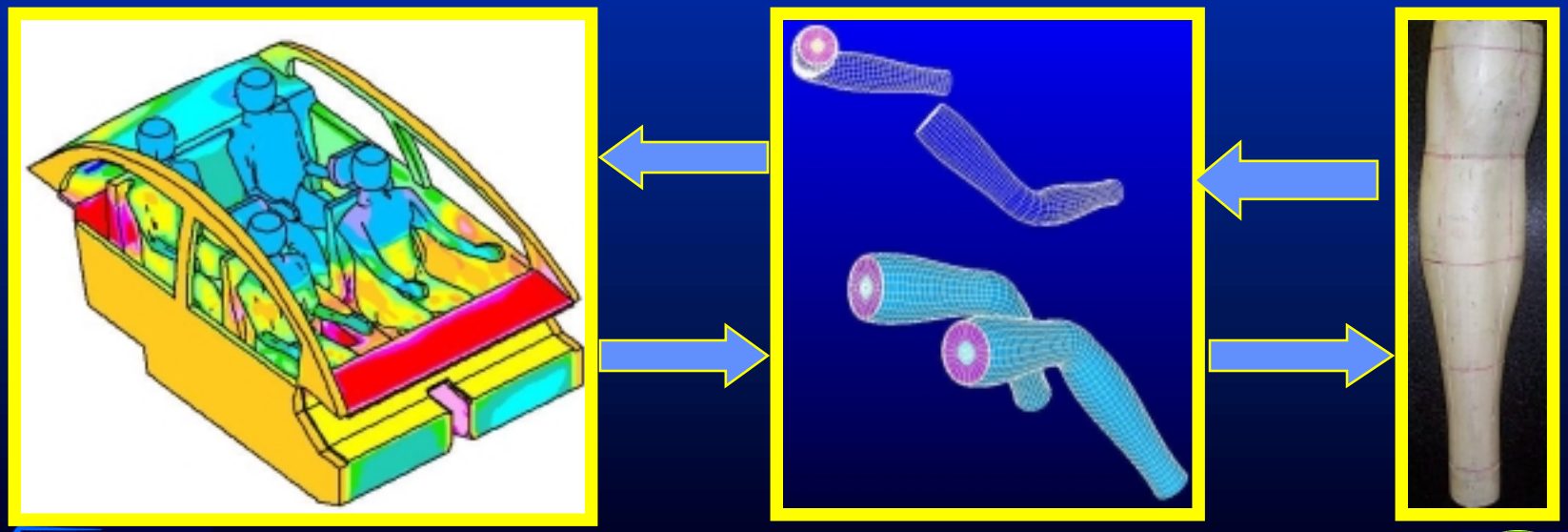


Need for Efficient Climate Control -- Honda Insight Prelim. Results



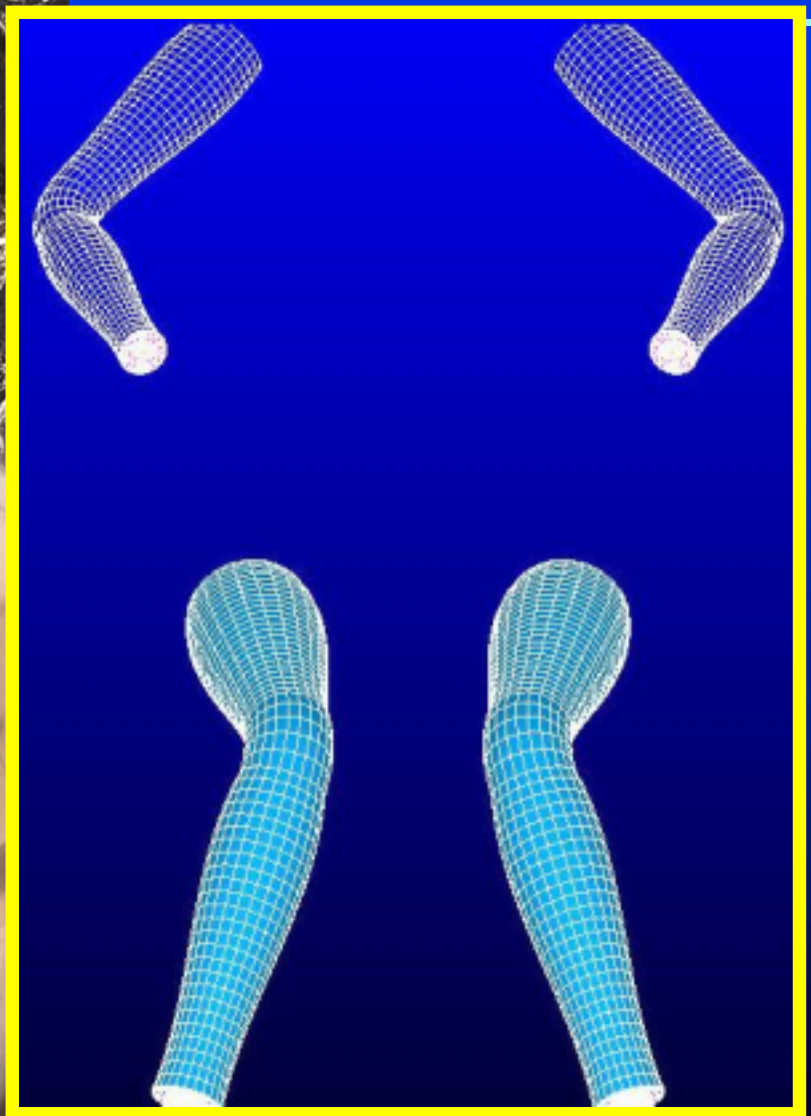
Integrated Modeling and Thermal Manikin for Predicting/Testing Occupant Thermal Comfort

- The Physiological Human Thermal FEA Model should be:
  - sufficiently detailed (anthropomorphic) to interact with cabin CFD models
  - sufficiently detailed to model the passive (tissues, bones, organs, ...) and the dynamically controlled systems (veins, arteries, heat generation, film coefficients, …)
  - flexible enough to provide data to the thermal manikin

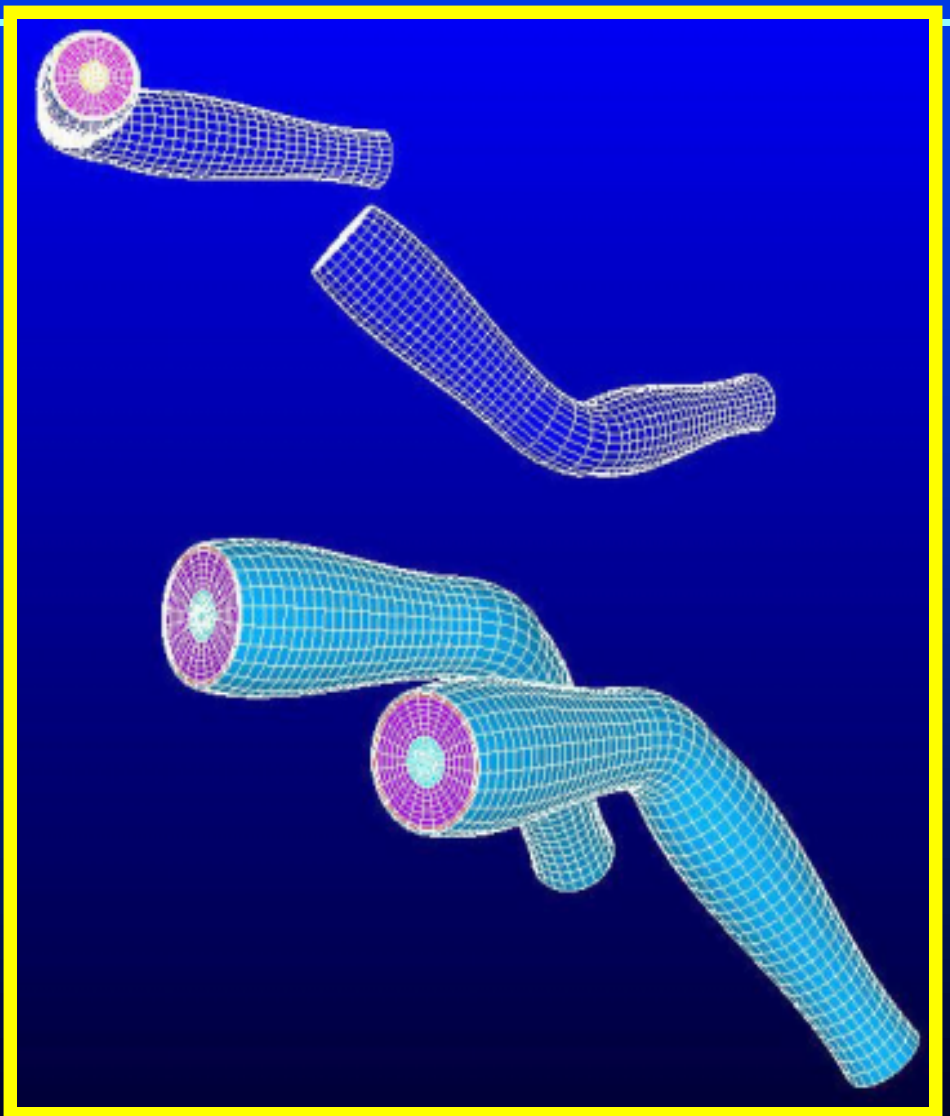


FEA model of lower & upper arms and legs

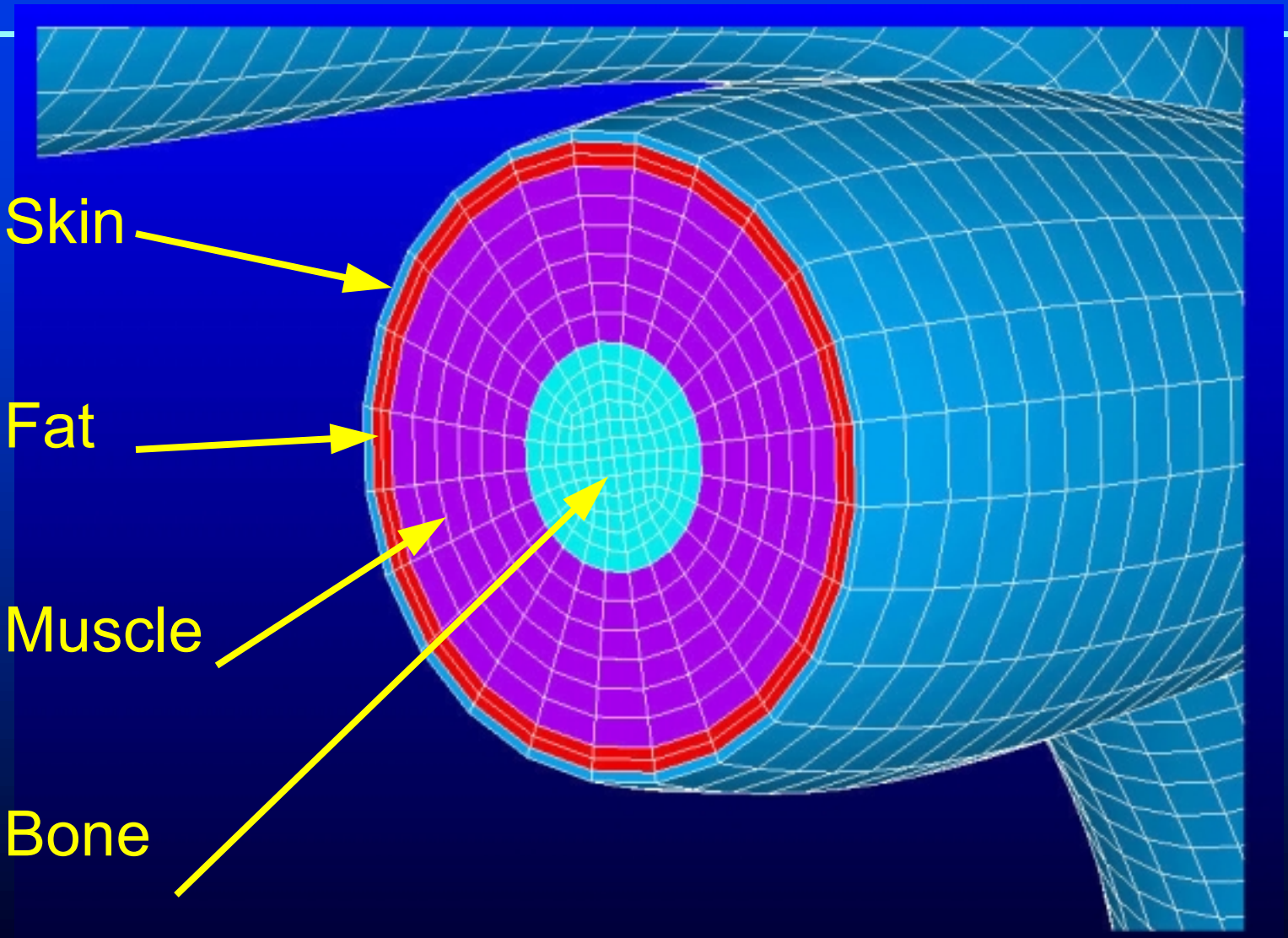
front view



isometric view

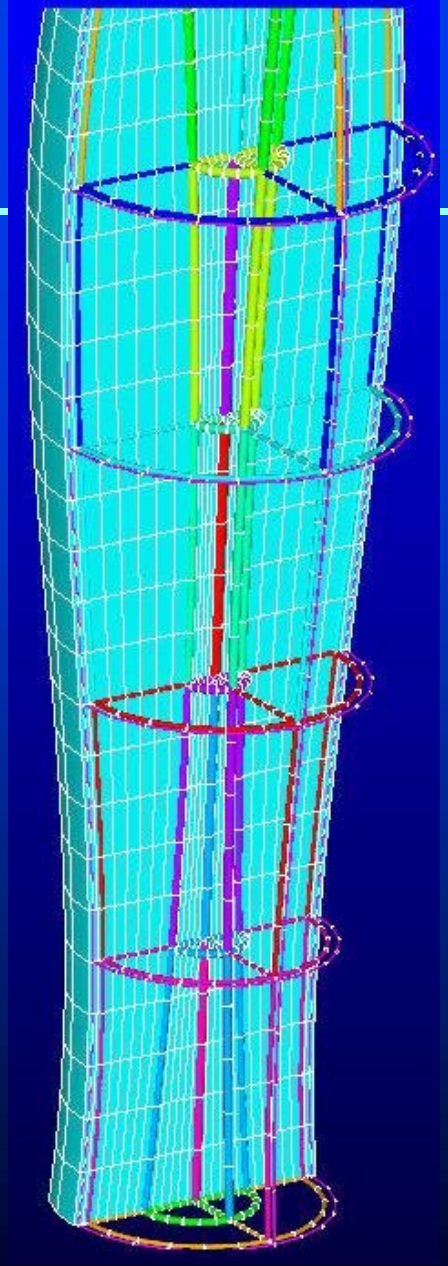


Section view of upper right leg's FEA model



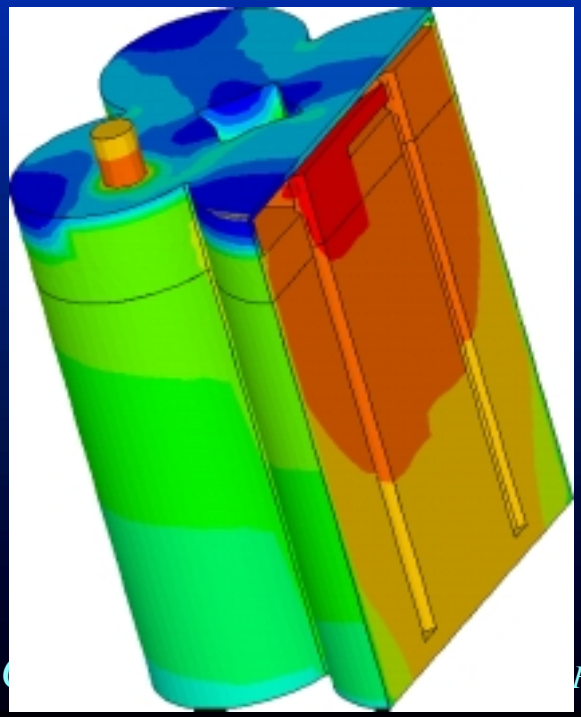
FEA model of the network of circular tubes at the lower leg

- Thermal-flow elements with the ability to conduct heat and transmit fluid between its two nodes
- Heat flow is due to the conduction within the fluid and the mass transport of the fluid
- Convection to the tissues is accounted with a film coefficient related to the fluid flow rate
- The cross-section of the elements may be adjusted at every time step to account for dilation or constriction



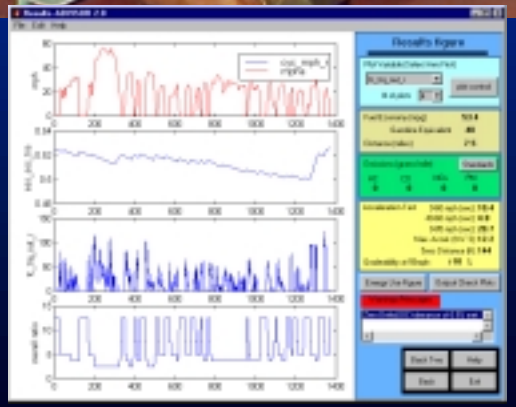
Outline

- Background and Capabilities of ADVISOR
- Demonstration of ADVISOR 3.2
- Optimization of a Fuel Cell SUV
- Digital Functional Vehicle
- Bonus: Thermal Effects on Batteries



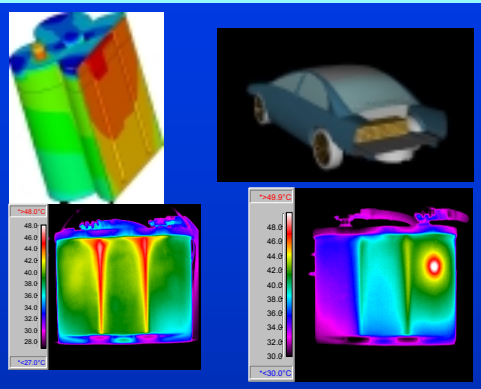
Battery Thermal Management: a Core Capability of the NREL's HEV Program

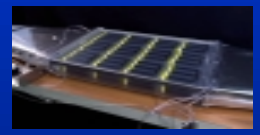
- Needs
  - Battery temperature affects vehicle performance
  - Battery thermal management is needed for achieving performance, life, safety
- Mission
  - supporting the DOE/OTT programs and industrial partners with thermal characterization, analysis, and performance modeling of batteries for improving performance, life, safety
- Focus
  - Thermal characterization and evaluation and cells, modules, and packs
  - Developing validated performance and thermal models for ADVISOR vehicle simulator

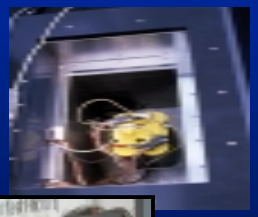


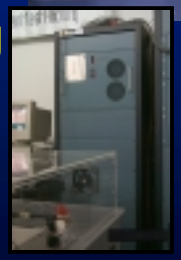
Multi-Dimensioned Approach for Battery Thermal Management at NREL

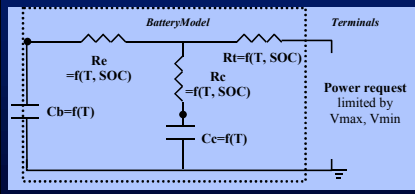
- Thermal analysis (CAD) for proper design, evaluation, and packaging of battery modules/packs
- Thermal imaging for evaluation and diagnostics of battery modules
- Fluid and heat transfer experiments for uniform temperature distribution and low parasitic power designs in battery packs
- Calorimeter/cyclers for measuring module heat generation and heat capacity
- Module cyclers for validated battery modeling for vehicle simulations
- Pack cyclers for benchmarking prototype and production battery packs





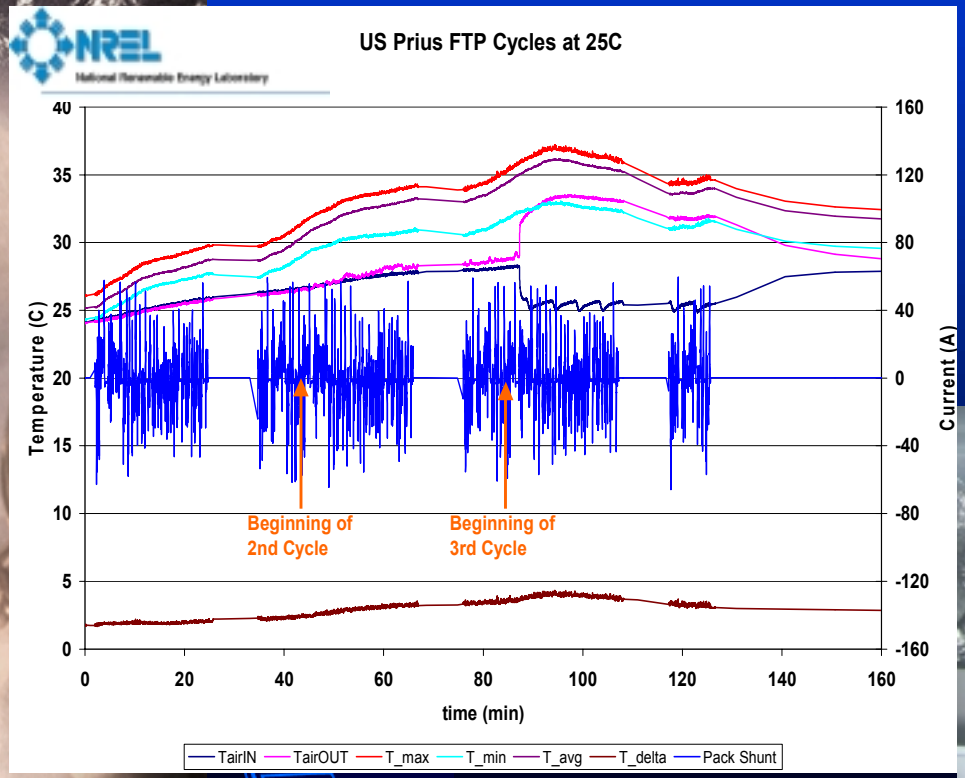


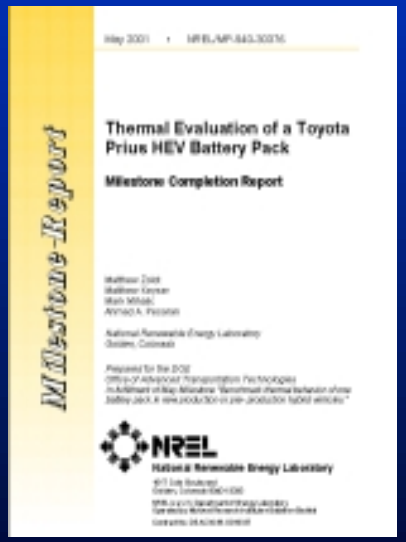




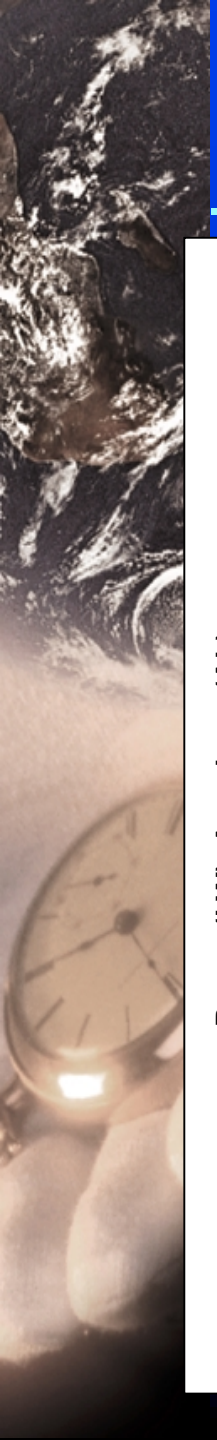
Benchmarking: Battery Thermal Management Systems in HEVs

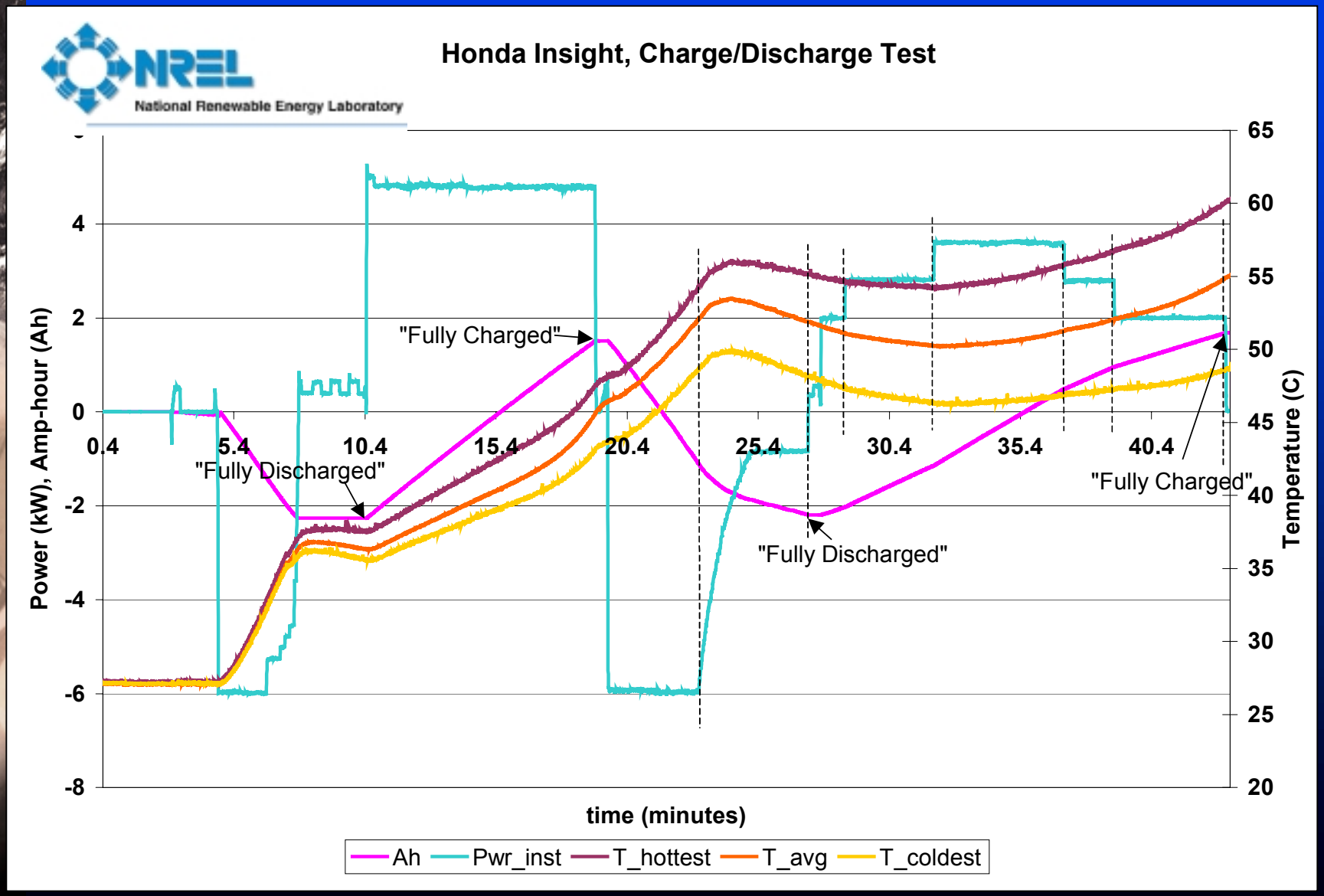
- Tested the Prius pack (out-of-the-vehicle) under various driving cycles and temperatures.
- Prius battery thermal management works well under most conditions, but its temperature distribution could be improved.





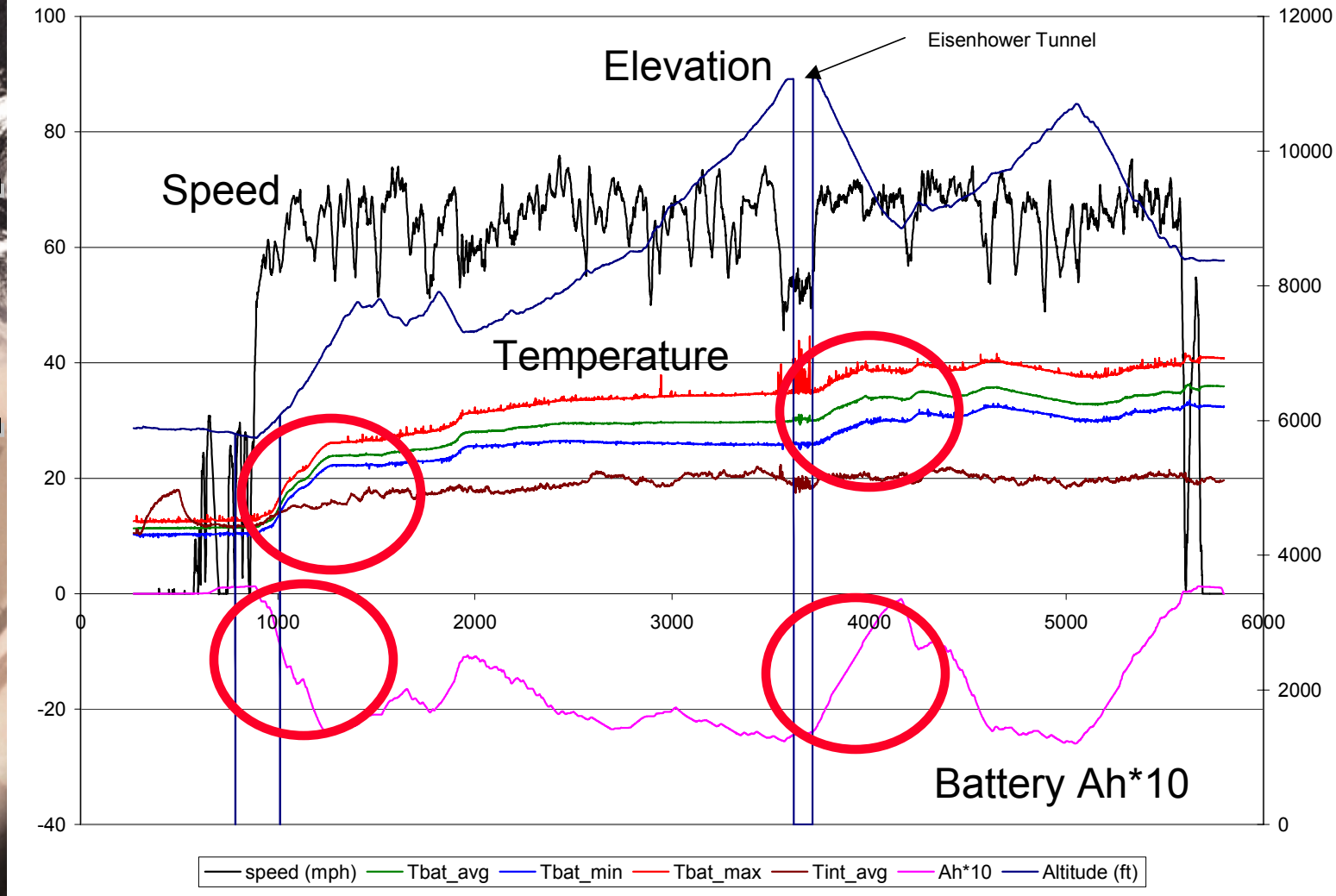
System-Level Energy and Thermal Management is Essential to Protect Batteries





Insight Test Data

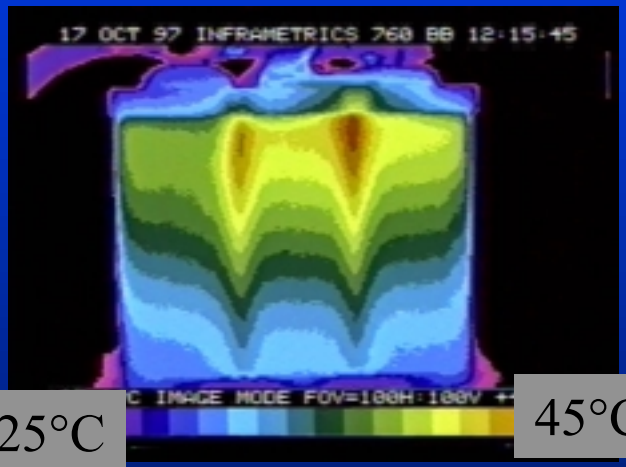
On Road Driving - NREL to VAIL



Thermal Imaging: Temperature Distribution is Dictated by Module/Cell Design

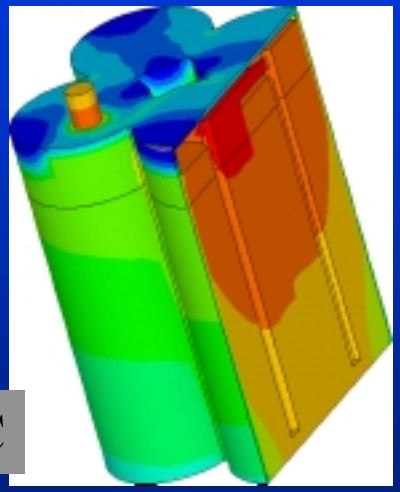
Factors: aspect ratio, # of cells, geometry, thermal conductivity, location of terminals, current density

Case 1

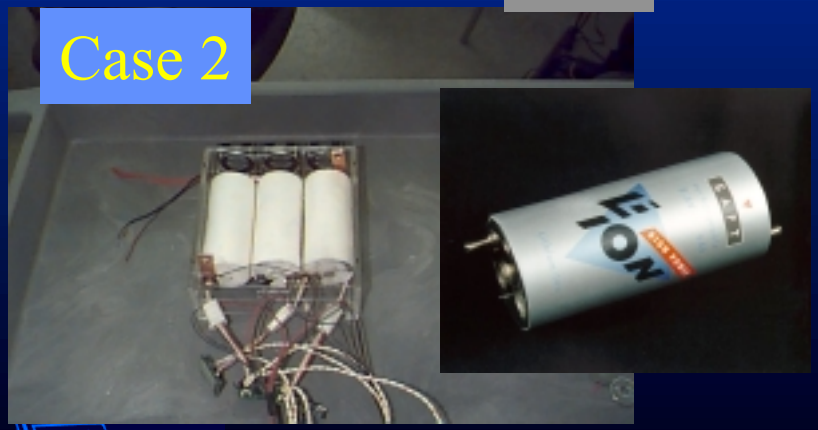


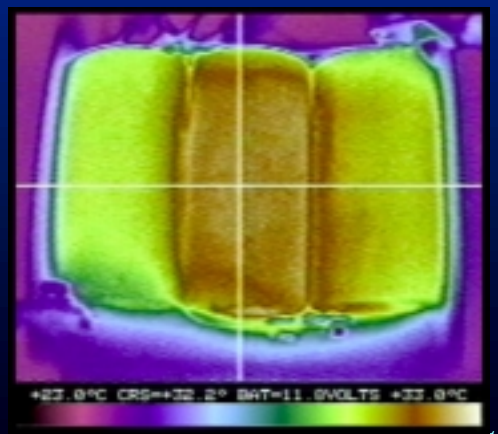
25°C

45°C



Case 2



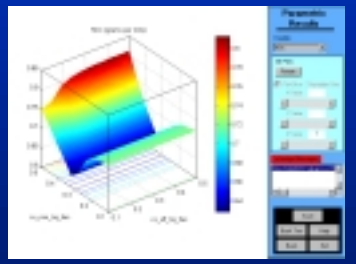


Only 2°C Difference

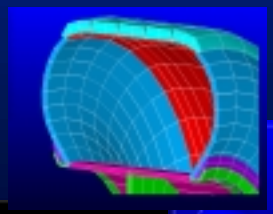
Summary:
Highlights of Vehicle Systems Analysis

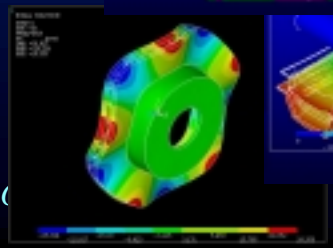
- *EVALUATION and ANALYSIS*:
  - ADVISOR a general vehicle systems analysis tool applicable to any type of vehicles (NEV to Class 8 trucks)
  - Thermal evaluation/testing of batteries essential
  - Thermal comfort of vehicle occupants critical to mission success

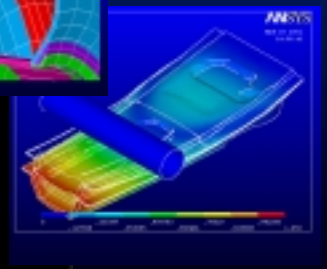
- *OPTIMIZATION*:
  - Once systems level tool are linked together, optimization can be wrapped around tools to obtain a better system level solution



- *COLLABORATION WITH INDUSTRY*:
  - Digital Functional Vehicle Projects are helping make energy impacts visible in industry analysis
    - energy focus
    - process oriented







Questions